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SYMPOSIUM ON "SEED IMPROVEMENT"

Leader: C. W. Warburton, U. S. Department of Agriculture.

1. THE IMPROVEMENT, DISTRIBUTION, AND MAINTENANCE OF FARM CROPS AS DISCUSSED FROM THE EXPERIMENT STATION VIEWPOINT[1]

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Just as big industrial corporations employ a staff of scientific experts to create new products or improve the old, so the agricultural industry of America maintains its corps of specialists at the state and federal experiment stations, striving to perfect the crops that are grown.

These crop improvement endeavors have been attended with a very fair measure of success. Comparative varietal values have been established. New crops have been introduced from abroad and tested. The principles of inheritance have been investigated and applied in plant breeding with very constructive results. The farmer is using these superior crops and, accordingly, is producing in greater abundance and enjoying greater prosperity. The balance

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of our population is likewise benefited, for favorable crop production is basic in the nation's welfare.

With regard to crop improvement, our agricultural interests are not only organized to develop and test new varieties through the experiment station service, but the effective distribution and maintenance of these crops has been enhanced by the more recent establishment of the state and federal systems of extension service.

How these two lines of service may best operate and cooperate with reference to crop improvement to the best interest of the grower at large, is to be the central theme of this paper. Other organizations which are natural factors in this problem are the various crop improvement associations and the organized seed trade.

SIGNIFICANCE OF SUPERIOR CROPS

In view of the large acreage devoted to the various important field crops in this country, the great import of even slight increases in the yielding capacity of the crop is readily seen. Enumerating several crops, the United States produced, in 1926, 99,492,000 acres of corn; 36,913,000 acres of winter wheat; 19,613,000 acres of spring wheat; 44,394,000 acres of oats; 8,200,000 acres of barley; 3,513,000 acres of rye, and 4,410,000 acres of grain sorghum This is a total of 216,535,000 acres of cereal crops, while 58,840,000 acres of tame hay were grown.

A single bushel added to the yielding capacity of grain per acre on this area would increase the total yield of cereal crops by more than 200,000,000 bushels This increase is accomplished through little added cost of production when resulting from the use of improved seed.

In so brief a period as the lifetime of the present farming generation there have been numerous cases of new crop introductions which have had a profound regional influence upon crop production. The wide-spread introduction of Turkey winter wheat in Nebraska and Kansas following 1890 revolutionized the growing of wheat. The new type yielded nearly two-fold that of the spring wheat which it largely superseded. Today these two states produce approximately 10,000,000 acres of winter wheat annually, as against a possible 200,000 acres of spring wheat.

The extensive adoption of alfalfa as the most important forage crop of the corn belt provides a second illustration. Thirty-five years ago this was an almost unheard of crop in the central United States. Today, a million and a quarter acres in Nebraska alone reflect the regard in which it is held.

And throughout this same territory sweet clover is coming into its own as a highly profitable dual-purpose crop. Only about 20 years ago this "contemptible" weed came to be recognized for its high grazing and rotation value and today is increasing in acreage by leaps and bounds. At that time one could probably have counted on the fingers of his two hands the number of Nebraska farmers who had intentionally seeded sweet clover. Today, this acreage is rapidly approaching a half million in this state alone. Why shouldn't it? Not only does this crop greatly increase the carrying capacity of the pasture wherever it thrives, but at the same time materially increases the productivity of the soil.

The introduction of early-ripening varieties of spring small grains materially increased the yields over the previously grown later-maturing sorts in much of the country where these crops are subject to heat, drought, and rust damage.

HOW NEW CROPS ARE OBTAINED AND APPRAISED

Aside from an occasional improved seed contribution by private individuals, superior new [illegible] from the systematic efforts of the various stat[illegible] stations, the work often being done in coll[illegible] ree distinct modes of procedure, *viz.*, (1) [illegible] seed of some new crop or variety from a fo[illegible] icing a new variety from another state, or (3) local improvement of an established crop through selection and hybridization methods.

EXPLORATION FOR NEW CROPS

It would seem advantageous in the main for the U. S. Department of Agriculture to serve as a central agency or clearing house in the matter of exploration for new crops and seed introduction from abroad. There would be a great deal of duplicated effort for states individually to make this foreign contact. Introduction by the government has brought us such new crops as Sudan grass and Cossack alfalfa. In still earlier years some of our most productive commercial varieties of wheat and oats were similarly brought into this country.

Promising new crops from abroad should be tested at the state experiment stations in those parts of the country where their history suggests they would be most suitable. With all of the agricultural exploration for new crops that has taken place the likelihood of further epoch-making new contributions by this means seems more remote than formerly. Both the U. S. Department of Agriculture

and the individual states are relying more upon the development of superior strains by crop breeding.

The procedure of crop breeding is largely along two distinct lines, *viz.*, (1) the selection, testing, multiplication, and distribution of superior individuals within a commercial variety; and (2) the hybridization of varieties or strains followed by selection, testing, multiplication, and distribution.

IMPROVEMENT THROUGH SELECTION

The principle of improvement through selection is based upon the fact that any long-established commercial variety consists of a grand mixture of individualities which differ in such characters as yield, quality of grain, earliness of maturity, vegetative size, hardiness, and resistance to disease and lodging. In the case of self-fertilized crops, such as wheat and oats, the process of improvement is relatively simple. For practical purposes it is considered that the initial selection of individual plants, heads, or seeds, followed by individual multiplication and comparative testing, comprises the entire program of improvement. The progeny of such a selection usually carry the same inheritance and further selection is unnecessary.

In the case of cross-pollinated crops, typified by corn, the matter is far less simple. Due to promiscuous cross pollination, every kernel on an ear of corn may represent a somewhat different inheritance. All of the plants of the progeny of even a single ear may differ from each other in some respect and non-uniformity is the rule. Furthermore, there are no existing varieties or strains of corn today which need not be kept in a thoroughly hybrid condition to be satisfactorily productive. Continual accumulative mass selection for specific plant characteristics will gradually modify the corn crop and in the case of an unadapted variety may result in marked improvement through making it more suitable to the local conditions.

IMPROVEMENT THROUGH HYBRIDIZATION

The greatest ultimate progress in crop improvement may be expected to come about through hybridization. Most of our standard productive crop varieties have certain shortcomings, while other sorts are especially strong in the same particulars. The procedure of combining the desirable characters of one variety or selection with those of another has become well established. Through a progressive series of hybridizations it should be possible to start with a productive strain of the well-known Turkey winter wheat and

transfer to it the extreme winter hardiness of Odessa, the smut resistance of Ridit, the stem rust resistance of Hope, the high milling quality of Marquis, and the stiff straw of some one of the soft red winter varieties. The Cereal Office of the U. S. Department of Agriculture and a number of the state experiment stations have such hybrids in various stages of development. While the recombination, selection, and testing of field crops is a long-time project, there are even today sufficient achievements to testify to the feasibility of the plan.

With corn, a constructive hybridization program is more involved. The crossing of two commercial varieties has seldom proved advantageous. During the last two decades it has been learned that a genetically sound procedure with this crop is to first develop a number of selfed lines through inbreeding, to be followed by recombination in single or double crosses or restored synthetic varieties. The best combinations are established through trial. In case of single and double crosses it is necessary to produce the seed annually in natural crossing plats because of decidedly reduced yield in the second generation, whereas a well constituted synthetic variety may be handled as any other variety.

EXAMPLES OF SUPERIOR NEW CROPS

Numerous examples might be cited of improved strains of various crops which have been developed by the experiment stations and have either come into extensive farm use or appear to deserve doing so. The following illustrations may suffice, Minturki winter wheat, Gopher oats, and Velvet and Comfort barley in Minnesota; Kanred and Tenmarq winter wheat in Kansas; Colsess barley in Colorado; Richland and Iowar oats in Iowa; Red Rock winter wheat in Michigan; Ceres spring wheat in North Dakota; Michikoff winter wheat in Indiana; Fulhio winter wheat in Ohio; Cornellian oats in New York; Progress spring wheat in Wisconsin; Oro and Regal winter wheat and Marketon oats in Oregon; Hybrid 128 winter wheat in Washington; Illred winter wheat in Illinois; and Nebraska 60 winter wheat and Nebraska 21 oats in Nebraska. Other states and countries have likewise made distinct contributions, too numerous to mention.

REGISTRATION OF NEW VARIETIES

In connection with the creation of new varieties by experiment stations and private individuals, it is of interest to recall that the American Society of Agronomy in collaboration with the Bureau of Plant Industry of the U. S. Department of Agriculture maintains a registration service for new improved sorts of wheat, oats,

barley. The plan provides for the registration of new varieties on the basis of performance, preferably at state or federal experiment stations. In 1926, 23 new varieties of wheat, 22 varieties of oats, and 3 varieties of barley were approved for registration, which is evidence that these committees are functioning. In addition to recording new creations, this registration should serve to maintain a high standard of performance requirements before such crops are distributed. Conservatism along this line is to be desired.

The commercialization of the new principle of corn improvement by way of placing upon the market single and multiple crosses between selfed lines is of relatively recent origin and there has been little opportunity to judge its practical merits in farm use. This mode of corn improvement may well be regarded as still in the experimental stage.

TAKING ADVANTAGE OF CROP IMPROVEMENT WORK IN OTHER STATES

The federal and local experiment station workers in many states are often working on similar problems to meet the various regional situations. In the case of crop improvement, many states maintain crop breeding projects. It is entirely plausible that the best new strain for any state may originate in some other state. Of course this can be determined only by trial. Among the most profitable work that any experiment station can do is to keep in touch with the crop improvement work of other states and to include the best new varieties developed elsewhere in their own tests. A nursery for preliminary variety testing may be maintained for this purpose, and the most promising varieties moved from this nursery to the more extensive field plats where they are compared with the best standard and other promising local sorts. Through maintenance of such a program Nebraska, for example, has adopted among its standard varieties Kanred winter wheat from Kansas, Burt C I 293 oats from Texas, Comfort barley from Minnesota, Marquis spring wheat from Canada, and Rosen rye from Michigan.

It should be the plan of such variety testing to maintain a systematic search for any new varieties that spring into local prominence on the farms of the respective states and to include them for comparison. Such tests provide much-wished-for information and either avoid undue exploitation or give a meritorious crop its just recognition.

NEED FOR RELIABLE PERFORMANCE DETERMINATIONS

A great responsibility rests upon the station workers who are charged with the development and distribution of new crops. From

the standpoint of scientific contribution it is important to know just how much improvement was actually effected by the particular plant breeding processes employed. From the standpoint of the farmer, it is desirable to know whether the apparent improvement is actual or mythical. Is he for a fact improving his production by substitution of the new variety for the old? From the standpoint of the extension specialist, the crop improvement organizations, and the seed trade, can such reliance be placed in the data of the station that the new crop may be recommended whole heartedly by them without the possibility of an embarrassing come-back? From the standpoint of the manufacturer and the consumer, has crop quality been maintained or improved in the new variety?

All reasonable precautions should be taken to insure thoroughness of testing in comparison with the other standard varieties available for farm use. Unless a new sort is actually superior, there is no justification for its distribution. Except in rare cases where the advantages are very conspicuous, superiority can only be established by careful experimental technic, involving comparable mechanical operations, replication of test plats to overcome soil inequalities, and comparative trial during a period of years of sufficient duration to overcome the misleading effects of seasonal variations. The peculiarities of individual seasons may tend to exaggerate unduly the effects of certain plant characters and it may be another 10 years before such a season recurs. Ordinarily, it is high average season performance toward which we should strive. This should steadfastly be borne in mind by all those concerned with the appraisal of new crops.

Stressing these points is not a case of sounding unnecessary alarm. Several experiment station workers have mentioned the premature distribution of certain strains which would have been forever withheld had they been tested even one year more. One station worker has indicated that his station had been rather expected by the state crop improvement association to supply them with a new selection of some crop every year and in an effort to meet this requirement at least one slip had resulted.

Undoubtedly, these are the things we must guard against. A sympathetic attitude on the part of the public for sound and conservative procedure is to be approved.

NUMBER OF VARIETIES SHOULD BE HELD TO MINIMUM

Stressing the value of holding down to a minimum the number of varieties of any one crop that are being grown commercially in a particular state or region, it may be pointed out that such standardization should aid in establishing a special demand for the uniform product.

In some states, due to restricted adaptation, a particular variety may not have state-wide superiority, and in such cases a number of special purpose varieties may be grown to advantage. The extent of superiority of any new crop may be best determined by the conduct of a number of outlying tests in various parts of the state. In some states regional substations and demonstration farms are available for this purpose. In many instances cooperative tests located on farms in various parts of the state furnish a splendid source for comparative information.

Such tests have maximum value if there is a personal follow-up by some trained worker. Superficial tests with poor technic may be misleading and do more harm than good. Mere estimates as to comparative yields are not reliable. Results secured by comparing yields of two varieties grown on neighboring farms or in different fields of the same farm have no specific value due to other unequal factors. Dependable methods should be used in these outlying tests the same as at a central experiment station. These comparisons are of serious concern and we cannot afford to go wrong.

Depending upon the type of state organization this cooperative testing may be done solely as experiment station work or cooperatively with the extension service. In any event it seems desirable that the agronomy extension specialists and the county agents should be aware of the tests and have access to them for holding field meetings and demonstrations

These workers are going to be responsible for arousing interest in any new crop of superior value. They will be largely instrumental in the wider distribution and maintenance of the improved seeds. It would seem a very desirable division of labor for the station service to produce and test new crops and for the extension service, cooperating with other existing agencies, to arrange for their wider use and commercial maintenance.

This brings us to the question of procedure in the commerical production, inspection, certification, and distribution of the seed.

We may admit perhaps, at the outset, that circumstances alter cases and we are more interested in the principles than in specific detailed procedure.

MAINTENANCE OF IMPROVED SEED SUPPLY

INITIAL SEED DISTRIBUTION BY THE EXPERIMENT STATION

After the desirability of farm distribution has been established through station and cooperative tests, the experiment station should undertake to grow a multiplication field of sufficient size to produce approximately 500 bushels of the new seed. This may be sold at reasonable cost to 50 farmers in 10-bushel lots. This amount of seed will grow sufficient acreage that the crop may be kept pure and furnish a foundation for further rapid increase in many communities. If a new self-fertilized crop is planted as part of a large field sown to a local standard variety, additional comparisons as to agronomic value may be made.

In the case of small grains there seems little justification in a charge for this initial seed supply exceeding about double the market price for commercial grain of the respective crops. In order to prevent a possible inclination on the part of some growers to overcharge for their seed the first year, when the demand may be especially keen, an understanding may be had to this effect at the time of the original seed purchase. Thereafter, supply and demand will usually hold prices at a reasonable level. This is highly important, since the seed improvement was undertaken for the benefit of the rank and file of farmers. The initial group of farmers to be supplied with seed are selected on the basis of their ability to care for the crop properly and willingness to comply with certain specifications in its production and further distribution. It is usually more exacting work and costs materially more to grow and market seed complying with certification requirements than to grow a crop of commercial grain.

It is evident at this point that cooperation with the members of a state crop improvement association, as exists in many states, is advantageous. Such individuals are likely to be progressive farmers who are business-like and equipped for this type of service.

INSPECTION AND CERTIFICATION OF FARM-GROWN SEED

After a crop is on the basis of commercial production, there is danger of admixtures with other varieties through seeding, threshing, and storage operations. Also, in the case of winter grains, these may be planted on land previously sown to another variety of the same crop with resultant mixing with volunteer grain. An efficient, self-supporting inspection and certification service, maintained under the direction of the extension service of the respective state agricultural colleges, is to be commended. This insures continuity of action and interest between the development and distribution,

the new crop and provides a very desirable "follow-up" observation on the farm. The responsibility of the institution is not completed with the development of superior strains, but extends to the multiplication and maintenance of a seed supply. Supervision of the field and bin inspection is a good type of extension activity in conjunction with a better crops program. It will aid in the avoidance of an over-commercialization of the better seeds movement. This work is done preferably in cooperation with the state crop improvement association. In practice, this arrangement has been widely adopted and is successful. The secretary of such an association is commonly selected from the agricultural college staff and most frequently is the agronomy extension specialist. Such cooperation is entirely wholesome so long as the association is democratic and membership is open to all who apply. It would be objectionable for the experiment station or the extension service to cater to any commercial group. Field inspection of the growing crop, as well as inspection of the seed as prepared for sale, should be required and stringent rules met to be eligible for certification. An inspection fee plus a sales tax placed on the individual growers will largely pay expenses.

The exact manner of organizing the inspection and certification differs in various states, but the details of organization and procedure are relatively unimportant if they arrive at the same final end of providing a satisfactory seed supply of recognized superior crops at reasonable prices. Some state organizations maintain only one class of inspected seeds which they call "certified." Other states have as many as three classes with such names as "Elite," "Registered," and "Certified," designating the progressive stages of removal from the original foundation stock.

A formal, systematic, and thorough program should be maintained in the inspection and certification work. The patronage received and the service rendered by the growers depend upon the merits of the seed, the respect of the public, the reasonableness of the prices charged, and the business-like attention to details.

FUNCTION OF SEED CERTIFICATION

One occasionally hears the unqualified recommendation that farmers should always plant certified seed. From the standpoint of the commercial grower of grain for market, who is not especially interested in seed sales as a main or side issue, there is no particular advantage in sowing certified seed provided he has access to another source of satisfactory seed of the same superior variety. After a farmer has procured certified seed there is no particular need for

having his crop certified for his own next year's seed supply unless he wishes to dispose of his crop as certified seed. As a neighborhood practice farmers are often able to keep track of a newly introduced variety for several seed generations without official inspection and certification. If one is definitely aware of the source and identification and reasonable purity and quality of the seed, it would seem that such seed may be sown without hesitation for commercial grain production. This is merely a matter of good sense.

Exaggeration of the importance of extreme purity should be avoided. If a new variety of wheat is introduced which is definitely 2 bushels superior to the standard variety now being grown, an admixture of 1% of the local variety would do little actual harm. An extensive admixture of different types of grain, such as soft wheat in hard, barley in oats, and rye in wheat, and the contamination with disease and noxious weed seeds should be especially avoided in seed purchases, as well as in the production of seed for home use. Seed which has passed field and bin inspection and has been certified against these undesirable features is always a safe source for good seed in regions where adapted and thereby fulfills a very useful purpose. The value of pride in producing pure crops is a factor that must not be lost sight of.

SEED TRADE MAY PARTICIPATE IN CROP IMPROVEMENT

There is a growing desire on the part of the seed trade to handle only field crop seeds that would be approved by the experiment stations. Such a program should be encouraged as it will aid materially in the more extensive use of essentially pure, adapted crops. This may be well illustrated by the present alfalfa situation.

There is no longer any question relative to the general principle that alfalfa seed becomes progressively more winter hardy the more severe the regional winter conditions to which the parent stock has become acclimated through several seed generations. At least Arizona-, New Mexico-, Texas-, Southern California-, and Oklahoma-grown common alfalfa seed are not generally suited to the more northern states because of winter susceptibility. It is, therefore, desirable that such seed be kept from the northern market and, certainly, if sold, the origin should be made very clear so that the farmer may reject it. It is even less desirable that alfalfa seed from Argentina, Africa, Italy, or Spain be sold in our central and northern states, but the recent federal legislation relative to staining all imported seed will place a natural check on their use.

Although the recent federal seed legislation makes illegal the misbranding of alfalfa seed in inter-state commerce, it does not require labeling as to the point of origin in this country. Alfalfa seed can still be sold merely as alfalfa seed and the farmer may never know its source. He may purchase fine-appearing seed in a northern state only to surmise correctly at a later date, when he needlessly suffers loss of the stand, that it was Arizona-grown. Or if he purchases the so-called Dakota No. 12 seed, he should know that he has Dakota-grown seed and not Utah-grown.

When we go to the seed house to purchase alfalfa seed and have a sample of "North West Grown" seed recommended to us and are unable to learn whether it is from North West Nebraska, Dakota, Montana, Wyoming, Idaho, or Utah, we do not get sufficient information to satisfy us. Here is a splendid opportunity for cooperation, the experiment station determining the actual needs of the farmer and the seed trade undertaking to supply these requirements.

The substantial forces in the organized seed trade are aware that a permanent prosperity and a consciousness of true public service is closely linked with the scrupulous handling of seeds that are highly productive for the territory in which they recommend them. If the experiment station is fulfilling its function efficiently, it will be in a position to serve in an advisory capacity for the seed trade as well as for others. There is seldom justification in exploiting some new crop in advance of an opportunity to determine its true value for farm use. Cooperation in this respect between the seed trade, the crop improvement association, the extension service, and the experiment station is highly desirable and is, in fact, a rapidly growing relation. This places a positive demand upon the experiment station to maintain fearless, sincere, experienced, practical workers.

A mutual understanding of all who are working for the rural welfare should prevent a repetition of undesirable attempts to get a corner on highly exploited seeds with or without merit, and place an exorbitant price on them with the tricky suggestion to the purchaser that he in turn will likewise profit from fancy seed sales, if he gets in on the ground floor. As illustrations of such promotion during rather recent years may be cited: (1) Sudan grass, selling at $5.00 per pound; (2) Huban sweet clover, selling at $5.00 per pound; (3) Hardigan alfalfa, selling for $10.00 per pound; and (4) Kota spring wheat, selling at $6.00 per bushel.

There have been instances where individuals or groups of persons have promoted crops without special merit. For whatever reason and by whoever this may be done, it is unfortunate and the business

of crop production should be protected against such occurrences. We need but refresh our memory as to the undeserved promotion of three wheat varieties at various times during the last 20 years, namely, Alaska, Stoner, and Burbank. These were distinctly cases of unjustified propaganda, since their recommendations were universal, without qualification as to their adaptation. In one case the originator landed in the penitentiary, in another a great national weekly magazine apologized to the public for having published an unreliable story extolling the wonderful merits of the new (?) crop, and in the third case the promotion of the new (?) wheat at fancy price per pound was short-lived, apparently because its lack of superiority anywhere and inferiority most everywhere was soon learned by its purchasers.

As a closely allied consideration, the recent wide-spread, unqualified and misleading promotion of certain seed corn treatments is suggestive of another opportunity for cooperation for the farmer's good. On the other hand, it is a true service to encourage the use of recognized disinfectants against certain cereal diseases where these are prevalent.

PERMANENCY OF IMPROVED VARIETIES

The matter of longevity of improved crop varieties before they should be renewed or replaced is of decided interest to all concerned. This is a problem of only rather recent concern and is in part an outgrowth of crop certification. We have no reference in this connection to the possibilities of mechanical mixtures which develop through seeding, harvesting, threshing, and storing, since these are avoidable, but rather the issue pertains to the hereditary constancy of the crop.

Although "running out" of cereal crops as a result of continued production in the same locality for a long period has often been mentioned as necessitating frequent renewal by fresh seed importation, there is very little evidence in support of this and much to the contrary. Undoubtedly, this bug-a-boo of the cereal crops may be laid to rest, so far as hereditary tendencies are concerned.

The distribution of hybrid segregates whose type has not been well fixed by selection may result in further segregation with more or less conspicuous non-uniformity. This may or may not be an actual detriment, according to the nature of the characters segregating.

In the case of ordinary mass varieties, the natural tendency is toward improvement rather than deterioration for a particular set of conditions as a result of prolonged growth there.

Pure line selections of self-fertilized crops should remain essentially constant for many years when grown on farms and mechanical admixtures are avoided. As produced on small experimental plats in contact with other varieties, a slight and variable amount of natural crossing may occur, with the result of introducing hereditary differences. The extent of this behavior varies somewhat with localities and appears especially prevalent when a strain is grown under conditions to which it is poorly adapted. Gross differences in type may be eliminated by roguing, except where their prevalence is so great as to be prohibitive.

The maintenance of a "registered" class of seed, which is grown more or less in isolation and which is continually subject to close roguing or mass selection, is serviceable in connection with the production of certified seed.

Due to their hybrid make-up, corn varieties are very inconstant, and through continual natural recombination and segregation of characters are subject to great change in type through both control and natural selection. At least in states possessing a rather wide range of climatic conditions, to which corn is especially sensitive, the wisdom of trying to maintain specific varietal standards accompanied by certification of corn varieties may be questioned.

It may be regarded as sound policy for an experiment station to stress the principles of mass selection whereby a farmer may select and possibly improve his own seed corn for home use. Being a full season crop, this should develop local types which are best for the locality.

Fully reduced selfed lines of corn, developed and maintained in connection with the new corn breeding program which is just gaining birth as a commercial possibility, are as constant as lines of self-fertilized small grains if grown in sufficient isolation and accompanied by roguing. These could justifyably be certified.

Single and double hybrids between such selfed lines of corn as now exist must be restricted to the first generation crop. Seed for commercial production should never be selected from such hybrid fields because of certain yield deterioration. Should synthetic varieties composed of a relatively large number of selfed lines come to be distributed, they would be subject to variability, though in a lesser degree than ordinary commercial varieties.

2. MULTIPLICATION OF IMPROVED SEED THROUGH SEED ASSOCIATIONS[1]

H. C. RATHER[2]

Farmers in Mason County, Michigan, bought some seed corn last spring for $4.50 per bushel. They thought they were getting cheap seed. At the same time, seed of over 90% germination which was certified by the Michigan Crop Improvement Association was being offered by the same local cooperative for $7.00 per bushel. Nearly every one who bought the supposedly cheap seed came back later and tried to buy the $7.00 seed, in order to make replantings. Those growers found that economy is not always a matter of price. They found that in buying seed it pays to be careful about germination.

A farmer in St. Clair County bought some "cheap" clover seed and sowed it on his wheat. In addition to the clover, this man found he had planted a liberal seeding of catch-fly, a nice sprinkling of mustard, and a host of lesser weeds too numerous to mention. He threshed in the field and burned the straw to save infesting the rest of his farm. This man learned a lesson about purity.

A Hillsdale County farmer started out to get a 10-acre field into alfalfa. He had heard about Grimm alfalfa, but decided to turn his farm into an experiment station and sowed only half of the field to the Grimm variety. The other half he planted to "just alfalfa." The second winter an ice sheet formed over the field—and he learned his lesson about adaptation. Half of his field had to be plowed up because the alfalfa was gone. The other half, where he had planted Grimm, produced successfully for several years.

I suppose, if people were left alone, most of the things teachers are trying to teach would be taught eventually by experience. But experience is the highest paid teacher on the pay rolls.

Farmers, as a class, are not foolish. They are demanding that the information they need to make their business pay be secured from a less costly source than personal experience. They have provided public experiment stations to find out the right way of things, and have added an extension organization to bring that information to them as quickly, as efficiently, and as effectively as possible.

State and federal experiment stations have been learning a lot about seed for agriculture, the success of which is directly dependent upon the use of seed without making costly mistakes. The infor-

[1]Paper read as a part of the symposium on "Seed Improvement" at the meeting of the Society held in Chicago, Ill., Nov. 17, 1927.

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mation which the farmer needs covers more than purity and germination, conditions of seed which are of vital importance but which may be learned quite easily by examination and a few days' test. But if the farmer plants seed wisely he must also know about its adaptation and possible productivity, and he evaluates it not merely on the basis of what it looks like, but on the basis of what kind of a crop can be expected from it under his specific soil and climatic conditions.

Experiment stations breed and develop entirely new kinds of seed, the merit of which is helping keep agriculture on a more stable and profitable basis.

Such work cannot be commended too highly. It is basic. But it also carries with it a responsibility. When the public has invested thousands of dollars in acquiring information, or has spent years of some good plant breeder's time in developing a more productive crop variety, the public is entitled to have that information in a form from which it may quickly derive benefit. In this instance, it has invested the money in the interests of agriculture and it expects farmers to benefit, for here the welfare of agriculture and the state as a whole are identical. A new variety should be made available to farmers as fast as it is possible to increase the seed of that variety and keep it pure and of good quality. That is a responsibility that rests on agronomic extension workers.

New varieties bred by plant breeders in public service are public property. The first release of seed of those varieties should therefore be made in such a manner that public interest will be protected. I believe it is a mistake to release such seed promiscuously and in small driblets. When the supply gets large enough, it may be advisable to have a part of the seed set aside as a source of small samples to be supplied to practically every one who inquires for it, such seed to be used for observational purposes; but this is not a satisfactory way to have seed of a new variety increased.

Farmers are not equipped to handle a spoonful, a cupful, a peck or even a bushel of seed grain, for example, and keep it pure. Usually, such small bits are never harvested separately, if at all. When an attempt is made to keep the seed by itself, mixtures in harvesting, threshing, handling, or storage are too apt to occur.

On the other hand, experiment stations are equipped to handle seed in any quantity from the rod row to the large field. In Michigan, it has become our policy to increase seed of a promising new variety on the station farm until several bushels, sometimes several hundred bushels, have been produced. The last stages of increase

are accompanied by varietal tests not only at the station but under field conditions in several sections of the state in cooperation with interested farmers. These tests are arranged for by the county agents and are directly supervised by the Michigan Experiment Station. They finally establish the worth and place of the variety. No seed is released for increase until the merit of the variety is definitely established.

When it does go out, this first release should go to seed growers equipped with machinery, knowledge, and experience to produce large yields of good quality seed and keep it pure. Good farmers are not necessarily good seed growers. However, in every state where crop improvement associations have been active, men have been developed who practice exceptional care in the handling of their crops. Year after year, because of their cultural practices, they produce crops of unusual quality. They have equipped themselves with tight bins, good mills, and other necessities for keeping seed pure. Other farmers and seed dealers have confidence in the quality and purity of the seed these men put out. Such growers, of known ability, should be the ones in whose hands the first increase of a valuable, publicity improved variety is entrusted.

As an illustration, the Michigan Station has just increased a new strain of barley. This barley resulted from a cross between the Michigan Two Row and the Michigan Black Barbless barley. The Michigan Two Row is a high yielding, white, two-rowed, bearded, and barbed variety, late in maturity; while the Black Barbless is early, short and stiff strawed, smooth awned and good in productivity, but objectionable because of its color and its persistent awns. The cross, to be known as Spartan barley, is even earlier than the black, very stiff strawed but longer strawed than the black, white in color, two-rowed and smooth-bearded, but the awns are deciduous and thresh cleanly.

During the past two years of varietal testing, Spartan barley has exceeded the standard variety in use in Michigan in every one of 10 or 12 tests at the station and over the state. While this testing has been under way, the variety has been increased until we now have about 250 bushels as the nucleus for introducing it to Michigan farmers; with 10 or 15 bushels set aside to furnish observational or trial samples to interested farmers and experiment stations.

Had small lots of seed been furnished to growers a year or two ago, most of them would have been lost and possibly one or two growers would have an increase of their own which might be exploited at unduly high prices. I have seen such instances. Instead, farmers

who have demonstrated their skill as seed growers have been chosen in 25 counties, and they will receive enough seed next spring to plant 5 or more acres. This seed is known as "Elite" stock and is sold to the growers under an agreement which insures increase for seed purposes, specifies certain growing conditions, and gives the Michigan State College a voice in the price to be charged for the seed next season, thus assuring against exploitation until there is plenty of seed when this matter takes care of itself. These farmers can handle 5 acres with their regular equipment and, if they are careful, they can keep it pure. From past experience, we are sure these selected growers will keep the seed pure. They have demonstrated their ability along that line. This is the starting point for the seed maintenance and improvement work of the Michigan Crop Improvement Association.

The Crop Improvement Association, open to any interested farmer, maintains an ever increasing supply of pure seed of the varieties most highly recommended for use in Michigan. It is also continually developing the kind of skilled seed growers I have just described.

The genuineness, purity, quality, and vitality of seed produced by these growers is protected by an inspection of the growing crop and threshed seed of the recommended varieties.

The inspection is paid for by the growers who get this service, and in Michigan costs each grower about $10 per variety each season. The inspection work is done by inspectors trained and supervised in their work by the Farm Crops Department of the State College. Certification of seed which inspectors have found to meet proper requirements, previously laid down, is done by the Michigan Crop Improvement Association, while the responsibility for keeping the seed which they sell up to these standards lies with the individual growers. Because of the grower's own self-interest, associations have no difficulty in maintaining that responsibility by keeping alert and on the job.

Certification of seed by a publicly supervised organization gives unbiased information about the purity, germination, quality, genuineness, and adaptation of seed—and the true value of a variety—information which a purchaser of seed must have if he is to make his purchase wisely, but much of which information cannot be had on mere examination of the seed itself.

The work of a crop improvement association must be considered as public work. At least, such an organization must be kept semipublic in nature if it is to serve public interest in the dissemination of seed.

The Michigan Crop Improvement Association is open to any farmer in the state. Its affairs are directed by a board of directors consisting of a president, vice-president, and six directors elected from the membership. The Michigan State College shares in directing the affairs of this Association by having the head of the Farm Crops Department, the plant breeders, and a part-time extension specialist, who acts as secretary-treasurer, as members of the board.

The extension worker looks after the affairs of the Association having to do with the supervising of the inspection and certification of seed but has nothing to do with seed sales. From his position he is able to build up a membership from every section of the state, so the organization is kept state-wide in service; he is able to make sure that the standards of quality are maintained; and he is able to play a large part in the training of the growers, that they may become better and more efficient seed producers.

The part which the college of agriculture plays in an association of this kind is such that the interests of the organization are always kept on a basis of state-wide service.

Experiment stations cannot afford to turn foundational seed of new varieties over to private interests, even private crop growers' organizations.

Operated strictly as a private organization, a crop improvement association is apt to center in one locality and think only of its own commercial interests. Admittedly, seed certification could be handled more economically if all the growers were in one community. Inspection would be much cheaper. Conceivably, a good outlet for the seed could be, and, in similar instances has been, developed; but public service is likely to be forgotten. If the benefits of an improved variety developed by an experiment station are to become state-wide, growers of pure seed of that variety must be located in every section of the state to which the variety is adapted, and not around one point, merely because there inspections can be conveniently and cheaply done. The grower living in the most remote section of the state must have available the service of seed inspection and certification at just as low a cost as the grower most conveniently located with reference to the headquarters of such an association.

Each grower then becomes a nucleus for the distribution of quality seed of the improved variety around his community. He must, of course, make a profit or he cannot continue to be a seed grower, but in growing and distributing this quality seed the seed grower not only profits himself, but he is also rendering a service to his community. The real excuse for crop improvement work lies in getting

under the general crop with seed of the best varieties, improving the quality of the general crop, and increasing the efficiency of its production.

As an illustration, we can take our own potato crop in Michigan. Michigan potatoes were once quite a nondescript lot, selling at a discount on the general market. Today, they sell much better because the bulk of the crop is of a standard variety, with quality vastly improved; for table stock growers have been getting under their product with carefully grown certified seed.

The extension worker in farm crops may be doing educational work by describing some good varieties to farmers and creating in these farmers a desire to make use of such seed in their business, but the extension worker's job is poorly done unless he can also direct those who want to follow his teachings to convenient sources of such seed at prices which make it a sound investment. In fact, educational work on varieties without dependable seed sources is worse than valueless for a farmer who buys Grimm alfalfa seed that never was Grimm, that may have been grown in a mild region and have no chance of standing a hard winter, thinks the talk about Grimm is pure bunk.

We will have to admit that in the past we have been in just that fix; and I am not blaming the seed trade, for they had no more means of knowing the genuineness of their seed than farmers did.

But organized production with an impartial, publicly supervised inspection system has given the trade sources of Grimm alfalfa upon which they can depend. The same is true of other varieties and kinds of crops. And those organizations not only protect variety and origin but they maintain high standards of purity and quality as well. Such seed sources are making possible the successful production of alfalfa where it never was a dependable crop before.

It is fitting, therefore, that the crops extension worker, in order to be sure of his seed sources, be closely associated with the producing and certifying organization, and that he at least be partially responsible for keeping the inspection and certification service at a high standard.

Such backing to the teaching of crop improvement is just as essential as is laboratory equipment to the teaching of chemistry.

The agronomist need not inspect seed himself, but he should train and supervise inspectors and see that they do a good job. He should also train growers in quality seed production and distribution. He should have a voice in the affairs of the producing and certifying organization so that he may be able to protect the interests of the users of certified seed, as well as the interests of its producers.

Five years ago we began working with a promising corn grower in Michigan and started him off on the principles of drying and marketing seed corn. Since then, he has built up a twelve to fifteen thousand dollar seed corn business with certified seed, part of it retail and part of it through the usual trade channels, to which he discounts his seed. However, I do not justify our work with this grower each season on the strength of the fine business he has built for himself. The real service we have rendered is through him to the growers of the 10,000 acres of corn planted with his seed. One farmer told me last month that every man who had planted a bushel of seed last season produced by this certified seed grower had made $100 on it because of the mature corn he had been able to secure. despite an adverse spring. Maybe that is putting it a little strong, but it at least shows that we are reaching the right people.

If a commodity lends itself to inter-state trade, as with alfalfa, clover, and potatoes, the service can well include the insuring of quality production and effective marketing of seed surpluses for the use of growers in other states who may find the seed desirable for their conditions.

The actual marketing of the seed is, of course, a private function. Since the growers of the main crop secure seed through several channels, it is desirable that certified seed move through every one of those channels. There is a great natural farm to farm movement of seed. A service is being rendered to growers if each year more of the seed in the farm to farm movement is of certified quality. Local elevators buy and distribute seed and many certified seed growers use this channel for the distribution of their crop, and are therefore improving the quality of seed handled in that manner. Others have contact with seed companies, both private and cooperative. A strong Michigan seed company is now contracting certified seed oats and corn with Michigan growers. Many Michigan growers market their surplus certified seed through the cooperative Michigan Farm Bureau Seed Service. A group of potato growers market certified seed cooperatively through the Michigan Potato Growers' Exchange. All of these movements have given tremendous stimulus to the use of better seed in our state.

We advise our farmers in Michigan to use Grimm and Hardigan alfalfa. To be sure of its genuineness, we want that seed certified and protected, sealed if necessary, by a public service which can reliably tell the things that cannot be told on examination of the seed itself. We do not care who makes the sale, if our growers have that kind of protection.

To my mind, the agronomist is in best position to give this protective information. The economist may know costs, supplies, and demands, or business methods; the salesman may know how to get business; the farmer may know how to produce, but his experience is likely to be limited to his own locality; but the agronomist knows crop varieties and how they perform under a wide range of conditions, and he can put that information to work through organization of carefully trained seed producers strategically located and associated with a public institution closely enough so it can never lose sight of state-wide service.

An agronomic extension worker responsible for educational work in crop standardization and improvement in his state is effectively getting his work before a great many people if he follows such a program. Long before local leadership in extension work was talked of as such, crop improvement associations were providing the most effective local leaders that have ever taken part in an extension program. The strength of such work is, and, I believe, must always be, based on the very close cooperation between an organized group of growers and the service in extension agronomy.

We estimate that members of the Michigan Crop Improvement Association this season will have produced enough seed corn, carefully stored and fire-dried and giving a strong germination of 90 to 95% or better, to plant 50,000 to 60,000 acres.

Kansas, similarly, reports that it will care for a considerably larger corn acreage with certified seed.

The start which our Michigan crop gets from seed of high germination, the sureness with which it matures because of adapted varieties, its productivity because of the superior yielding ability of those varieties will easily make it possible for the users of that seed to earn from $150,000 to $200,000 more than they would out of their corn with seed less carefully handled. In an adverse season the margin of profit may be much greater.

That is a direct benefit from certified seed. This benefit, however, is accumulative because of the great use of seed of improved varieties only a few generations removed from actual certification. The value of maintaining quality foundational seed stocks of mproved varieties in corn, wheat, oats, rye, barley, beans, alfalfa, and potatoes, through a seed association directed by agronomic extension workers in Michigan mounts up to several million dollars each season. Twenty states have similar organizations banded together in the International Crop Improvement Association, each of which is rendering a like service to its state. It is a national program which is doing its part to keep American agriculture on a stable and permanent foundation.

3. SOME PROBLEMS OF SEED IMPROVEMENT AND DISTRIBUTION[1]

FRED W. KELLOGG[2]

The seed supply has been the subject of debate for years. But unfortunately, each of the agencies interested in this vital agricultural question have debated it very largely from its own viewpoint. Perhaps certain prejudices have served to belittle the opinions, advice, and counsel of the agencies of which we were not a part. Happily, there has been a complete change of attitude during the past two years. The Seed Marketing Conferences, arranged by the Bureau of Agricultural Economics of the U. S. Department of Agriculture, brought us together for the first time to discuss a problem of common interest. Representatives of all of the agencies worked together harmoniously on the committees of the Conference. It was found that little conflict existed in the point of view of the committeemen or in the general conference toward the proposition under discussion.

Conferences such as this would be of untold value if they served no other purpose than to promote a closer acquaintanceship between the agricultural workers and the seedsmen who are devoting their lives to the service of the country's most important industry. But better acquaintanceships invariably break down prejudices and create a sympathetic interest and understanding of common problems. There are few problems, no matter how complex, that will not yield eventually to the close teamwork of a group of conscientious men. Questions relating to the seed supply will not prove an exception, if we ever keep in mind that the interest of agriculture is paramount in every situation.

In giving our consideration to the question of "Seed Improvement and the Distribution of Seed," from any viewpoint, we must recognize a situation peculiar to agricultural seeds. These seeds are produced by farmers and are consumed by farmers. Thus one set of farmers may be likened to the producer of the raw material, while the other group is, or should be, the ultimate consumer of a finished product. The interests of the one are antagonistic to those of the other. The principal concern of the grower of seed is to receive the highest possible price for seed, weeds, dirt, and all, while the consumer looks for the highest grade at the minimum cost. These are the real opposing groups and the seed cleaner and distributor simply

[1]Paper read as a part of the symposium on "Seed Improvement" at the meeting of the Society held in Chicago, Ill., Nov. 17, 1927.

[2]President, Kellogg Seed Co., Milwaukee, Wis., and Past-President, Wholesale Grass Seed Dealers Association.

performs a valuable service between them. It is obvious, therefore, that little improvement in seed qualities may be accomplished for the consuming farmer without the cooperation of the producing farmer. Nor will it be possible to raise immediately the general standard very much above the level of the present available supply plus the skill of the expert seed cleaner.

An attempt has been made to control the production of seed and the spread of dangerous weeds through a program of legislation. Pure seed laws, noxious weed laws, and laws to control live weed seeds in manufactured feeds have been enacted in many of the states. They have either partly or entirely failed in their purpose for several reasons. Either through the exemption of certain classes, as in the case of uncleaned, untested seed distributed by the producer; or through the failure to enforce their requirements, as is the case of more than 30 state seed laws; or through inability to compel the impossible, as in the case of the noxious weed laws.

There is no justification for laws forbidding the production of poor seeds, because nature is the offender and is not amenable to law.

The production of seed is always uncertain, being subject to many conditions beyond the control of man. It is in the same category as the production of all farm crops, and we may have a surplus in one season and in another a shortage of the seed needed. The quality of seeds is likewise beyond control both as to germination and as to purity, both being subject to the whims of nature.

The problem is especially complicated because of the desire to control the quality of the finished product, while the raw material entering it is never uniform or often alike as to the nature of its imperfections. The seed supply for American agriculture is of vital importance to the economic welfare of the nation and it is proper that it be properly safeguarded. This has been the purpose of the wave of regulatory seed legislation which swept the country during the past quarter century. That it has failed to control effectively but a small proportion of the annual seed supply is obvious from a casual examination of the facts. More than 40 of the states have passed some type of seed law and yet less than 10 of these laws are being adequately enforced. Instead of repealing a law which they do not pretend to enforce, the states permit their citizens to rest upon the false securities provided by the unenforced requirements of the law. Many of these laws contain a curious provision which exempts the grower from any of the responsibilities or penalties they provide. By this stroke of the legislative pen, almost half

of the agricultural seed used or distributed in this country was freed from any control or restriction whatever. For it has been estimated that less than half of the agricultural seed consumed annually passes through the hands of expert seed cleaners. The remainder is planted on the premises of the producer or distributed by him to neighboring farms. Failure to enforce some 30 seed laws has effectively removed a very large percentage of the balance. It is apparent, therefore, that only a small percentage of the annual consumption of seed is subject to any regulation whatever, and we wonder why our program of seed regulation has failed to provide the needed benefits.

To the numerous state laws, the federal government recently added an inter-state section to the federal Seed Act. This section seeks to prevent fraud or misrepresentation in the sale of seeds passing in inter-state commerce. However, there seems to be little disposition or means provided to enforce its requirements, consequently it may be added to the other dead letter seed legislation.

If all of the laws were strictly enforced and the farmers were brought under the same requirements as other vendors, we would be confronted with a seed shortage because of the great quantities of seed that could not be brought to legal standards by any purifying methods now available. That the general quality of agricultural seeds as produced on the farms is deteriorating each year is perfectly evident to anyone who has closely observed this development over a period of time. The significance of the situation has not been apparent to the casual observer because of important accomplishments in the art of seed cleaning in recent years. Nevertheless, it is an economic waste to produce seed so badly infested with weed seeds that from 10 to 20% or more of the bulk must be sacrificed in the process of cleaning and purification. It is not uncommon this season to see lots of alsike, white, and red clover seed which contain from 10 to 50% of sheep's sorrel. Or these clovers contaminated with more than a thousand times as much Canadian thistle, buckhorn, or other noxious weeds as are permitted under the requirements of any seed law.

The contamination of the land advances many fold under each replanting of home-grown, untested, weed-infested seed. Each succeeding crop is immeasurably inferior because of the prolific seed-producing tendencies of many of the weed plants. In some of the seed-producing territories it has been the practice of some producers to have their clover seed recleaned, dispose of the clean seed, and take the screenings home for replanting there. Others purchase highly recleaned field seeds and plant them with uncleaned, weed-

infested seed grain. Field seeds contribute generously to this contamination, but uncleaned seed grain is even a greater offender.

"The enormous weed crop that is raised with grain every year is one of the chief reasons we do not have larger yields of grain per acre in the spring wheat area." This is the opening statement of U. S. Department of Agriculture Farmers' Bulletin 1542 entitled "Cleaning Grain on Farms and in Country Elevators." "Many cars of spring wheat containing over 20% dockage are received at the terminal markets each year from the spring wheat area. The cost of the freight on the dockage must be shared by each bushel of net wheat in the car, because payment for the wheat is made on the basis of the number of bushels of net wheat only in the car. The loss in freight alone is from 3 to 6 cents per bushel on the net wheat in the car, depending upon the freight rate." Then there are other losses—decreased yield, contamination of the land, and loss of labor in handling the weed portion of the crop before and after thrashing.

This bulletin contains interesting data upon the "Weed Tax." In the long list of present day taxes, the "weed tax" is never listed and yet its toll in reduced yields and inferior produce, if tabulated, would reach a staggering sum.

We seldom consider thrashing operations as a possible contributor to existing evils. The cost of harvesting grain and seed crops is usually computed upon a bushel basis. Obviously, the expense of thrashing weeds is as great or greater than for grain. Unless the grain and weeds go into the bag together, the thrasherman will not be paid for his entire service. The interest of the farmer would be best served, however, by making at least a partial separation of the weeds at the thrashing machine, even though he paid the full price for thrashing them. This would forcibly illustrate the high cost of the "weed tax," because the farmer could not restrain a mental calculation to determine the percentage of his fields devoted exclusively to the production of weeds.

Now I am sure it is perfectly apparent to all of us that we are discussing a real farm problem and one which undoubtedly contributes in no small degree to the "farm situation" which at this time seems of pressing national importance.

We seek means by which seed may be improved toward the end that our farmers may enjoy larger yields per acre and a lower unit production cost. It costs about the same to produce and harvest a poor crop as a good one. Therefore, an increased yield of improved quality would greatly reduce production costs. Double the yield and the costs are almost cut in two.

If our seed production was centralized in restricted areas, or conducted in large units by a limited number of growers, the problem would be simpler. The case of Grimm alfalfa illustrates what may be accomplished under intelligent direction, when production is upon a large scale in rather limited areas. Under the uniform system adopted by the states of Montana, Idaho, and Utah, Grimm alfalfa true as to variety, of high purity and germination, with a weed seed content under certain control, has been made available in large quantities. The leadership responsible for this development is deserving of the highest praise.

The other clovers are beyond similar control because of the wide areas in which they are produced and the thousands of growers involved. Furthermore, it is not always the purpose to produce a crop of seed, but when other farm conditions are favorable, a farmer will decide to let a certain field go to seed. But if he were striving to produce a forage crop of high quality and containing a minimum of weeds, the question of the purity of the seed would be largely solved. It would appear, therefore, that the solution lies in more intelligent farm operations.

Any great improvement to be effected in seed qualities will be in that portion which does not pass through the hands of the expert cleaner or responsible commercial seedsman. Agricultural seeds of dependable quality in point of adaptability, purity, freedom from noxious weed seeds, and power to germinate are obtainable under the trade-marked brands of reliable and responsible seedsmen. Dissatisfaction and disappointments in respect to seed purchases usually result from a disposition upon the part of farmers to save money on their seed bill.

There are bargains in seeds, but these are to be found in these high quality, trade-marked brands. Seeds under these brands are sold with a far lower margin of expense and profit, when the nature of the service is compared, than any other agricultural product. The matter of price should be the last element to be considered in seed buying. Cheap, trashy seeds of unknown quality are the most expensive regardless of the initial money cost. Dependable seeds are a farm investment and the investment, if made wisely, will return large dividends.

Someone may say "we ought to have a law," but there is no need to burden the statute books with added laws. We have expected to cure by legislation far too many of our national problems, and we need not depend upon legislation alone for relief in the situation we are discussing.

We all realize the consumer of seed is justly entitled to every safeguard which may be provided through the operation of reasonable, workable, regulatory seed legislation, adequately enforced. Therefore, I believe the present seed law situation is deserving of thorough, intelligent study toward the end that the requirements of the several state laws may eventually be made as uniform as the local situations permit. A simplification of seed laws need not remove any necessary protective feature, but it would result in a clearer general understanding and economies to those distributing seeds in several states.

The quantity of seed distributed by the producer is so important that, if regulation and control are to be effective, the provision in state seed laws exempting such distribution should be repealed.

In order that an adequate supply of seed may be available for distribution under the requirements of all laws when properly enforced, our consideration must be given principally to an improvement in the supply of raw materials. There is no necessity of passing a law forbidding the production of forage crops or seed crops badly infested with weeds or weed seeds. Such improvement may only be expected from an awakening of the self-interest of the individual farmer. He needs to be shown the folly of devoting his land, labor, and machinery to the production of partial crops. Show him how a small added investment in high quality, adapted seed and a moderate charge for removing the weed seeds from his seed grain will pay handsome dividends and he will be interested. Nothing is more convincing than an illustration which strikes through the pocketbook. He will cease replanting uncleaned, untested, weed-infested, home-grown seed and uncleaned seed grain only when he realizes that by so doing he cuts his net money return.

The present condition of our forage crops and the production of seed is the development of many years and the paramount question is not "how to prevent the introduction of weeds," but "how best to avoid further spread and to lessen the loss caused by those we already have with us" My experience has been wholly with seed, so aside from stressing the importance of cleaner seed and seed grain, I do not feel qualified to discuss effective cultural remedies. However, whatever these may be they may be expected to be effective only when generally applied where needed.

The development of new and improved strains of seed and seed grain is of great importance and the splendid efforts of our agronomist friends should be commended and this development continued. But unless a broad, comprehensive program is successfully developed and prosecuted for the control of the weed situation, we may not

expect too much from improved strains because weeds are likely to offset the possibility of a better yield or other benefit.

This "weed tax," as I have said, takes a staggering sum from our national agricultural income and, in my opinion, a successful solution is of vital importance to the economic welfare of the nation. Ten million dollars was appropriated by the last Congress to fight the spread of the European corn borer, and yet practically nothing is being done in a situation which, if allowed to continue, may be quite as serious.

The solution, if there be one, lies in an appeal to the self-interest of the individual farmer. It is a matter of education, but education upon a more intensive scale than ever attempted in the agricultural life of this country. Facilities and personnel are available to formulate a program, but its succsessful prosecution would require the earnest cooperation and financial aid of many of our national agencies. The American Bankers Association, the Chamber of Commerce of the United States, the national and state departments of agriculture, every industry whose prosperity depends upon the welfare of agriculture, and the agencies to be represented in the Central Seed Council of North America should have a genuine interest in such a program. If no other benefit should be derived than the saving of a part of the money expended to handle and transport the dockage in one year's grain crop, the effort would be well worth while.

This educational campaign, in my opinion, could only be successfully conducted by a well organized, adequately financed, publicity bureau under the management of an able, experienced publicity manager.

The fullest cooperation might be expected from the editors of the farm journals and, in fact, from the press of the entire country. Some may say much information is now available on the subject of weed control in the form of farmer's bulletins and I am sure there is. But there is no organized means of disseminating it. In fact, a casual and occasional reference to the wastes caused by the spread of weeds would have but little effect. "To control the alarming spread of weeds, to promote the use of better, cleaner seeds and seed grains, and to eliminate the obvious wastes of agriculture" should be the appeal of the campaign. And this appeal must be kept constantly before our agricultural population through the use of every means of publicity. The radio, moving pictures, news items, editorial comment, lectures, bulletins, placards, and powerful display advertising could all be profitably utilized.

The problem is surely of sufficient importance to warrant a national publicity campaign upon the same scale as our great manufacturing institutions employ to promote the use of their products in every city, village, and town and at every cross roads place in this great country. Millions might be added to the annual agricultural income through but a partial solution of the problem. A simple illustration or two will suggest the value of the prize at stake.

Quite recently I had the opportunity of examining the account sales covering four cars of Early Fortune millet seed shipped from the Dakotas to Milwaukee. These cars contained a total of 147 tons of Early Fortune millet, weed seeds, and other dockage. The mixture sold at $38 per ton, less dockage, which on the four cars averaged 24½%. The Early Fortune millet amounted to 111 tons and brought $38 per ton. But the shipper received nothing for the 36 tons of dockage, although he paid $273 in freight charges to haul it to market. The dockage he had given away had a market value for feeding purposes of $15 a ton, or $540 for the 36 tons. If this dockage had been cleaned out before shipping the millet and sold separately for feed, the return on the transaction, after paying cleaning charges, would have been several hundred dollars greater. Profits in industry have been greatly increased in recent years through the elimination of waste. Imagine any industry looking to the government for relief when such opportunities exist for profit as lie in the wastes of agriculture.

It has been estimated that the dockage in the wheat crop of North Dakota alone, if removed and retained on the farms, would have a feeding value of more than $5,000,000 annually. Add to this similar wastes in the other wheat-growing states and the losses, resulting from decreased production of inferior produce, contamination of the land, harvesting and labor losses, and all of the other items making up the "weed tax" against other farm crops, and no one knows what the total would be. The "weed tax" may be $200,000,000 annually and it may be very much more. Unfortunately, there are no statistics available on the "weed tax," because it is assessed indirectly against countless thousands of farmers. But it is being paid just as surely as are any of the other taxes for which tax bills are rendered each year.

If it is sound national policy for the Congress to appropriate $10, 000,000 for a year's campaign against the corn borer, I am sure it would be equally sound for it to appropriate say $1,000,000 annually for a period of 10 years for the conduct of a campaign to solve a problem which in time may be equally serious.

The weed situation is recognized in many quarters as a serious menace to agriculture. It is time an effective means is found to control it. It is a matter deserving of the thoughtful consideration of the U. S. Chamber of Commerce and the other institutions I have mentioned and of each of the agencies represented here.

Adequate means for the distribution of agricultural seeds are of vital importance to agriculture. To be effective, such distribution must make seeds available to the consumer when and where they are wanted and of the kind and quality needed.

It is interesting to note in the matter of most agricultural crops that consumption begins almost immediately after harvest and continues throughout the crop year. Again seeds are the exception. They are harvested in the season of other crops, but practically the entire production remains unused six months later. While other crops are being turned over and over during the year in the process of consumption, farm seeds have but one annual turnover. When weather conditions are unfavorable at seeding time, some varieties do not turn that often. The process of distribution commences following the harvest season, when seeds move from the farms to market and into the commodious warehouses of seed merchants. Here they are carefully sorted and graded and examined for purity, and the weed seed content and growth determined. They are finally expertly assembled to the grades required and are then passed through processes of cleaning and purifying as comprehensive as those employed in many manufacturing establishments. After recleaning, the seed is packed in bags and representative samples carefully drawn, and these are again subjected to expert analysis and examination to determine the purity, weed seed content, and power of growth. Cleaning operations, which formerly required hours to perform, now require as many days. "Once through the mill" does little toward providing seeds of present day standards.

The process of distribution continues by the movement of the seeds from the cleaning plants to stragetic positions located throughout the country. The movement progresses from these reservoirs of supply toward the farms where the seed is to be consumed during the short seeding season. To effect this orderly movement and to make ample supplies available to the consumer where, when, and of the kind and quality needed is the function of the seed trade. It is unnecessary for me to enumerate all that this involves. Suffice to say, it requires commodious warehouses, well-equipped cleaning plants, expert, experienced, trained personnel, and sufficient capital and bank credit to carry the season's production from harvest through to seeding time.

This service, which is of inestimable value to American agriculture, is performed at a lower cost for expense and profit than for any other agricultural commodity. The function of the seedsman is so little understood that sometimes we hear he exacts a toll unwarranted by the nature of the service he renders.

A simple illustration will suggest the wide difference in gross profits charged for handling seeds and for converting some farm products. For example, a bushel of wheat will buy, at retail, approximately 8 pounds of corn, when converted into cornflakes; or it will buy about 17 pounds of oats in the form of oatmeal; or less than 3 pounds of hogs, when bought as bacon. But the same bushel of wheat will buy about 22 pounds of recleaned timothy seed, or almost 5 pounds of hardy common alfalfa, or between 3 and 4 pounds of medium clover seed. But the interesting point is in noting the costs of the farm materials entering these items which the same bushel of wheat will purchase. Eight pounds of corn in cornflakes costs about 12 cents; 17 pounds of oats for oatmeal around 27 cents; and approximately 2½ pounds of hogs in bacon approximately 25 cents. But the cost of enough country-run seed to make 22 pounds of recleaned timothy is about 92 cents; or 5 pounds of hardy common alfalfa 95 cents and medium clover a little more than a dollar. It will be well to remember cornflakes, oatmeal, and bacon are being consumed every day, while seeds have but one short consuming season during the year. And yet the costs of the seeds are from four to eight times the costs of the farm materials entering the other articles. There are manufacturing processes involved in the conversion of corn, oats, and hogs and wastes due to discards and by-products, and other materials and containers add to the costs of cornflakes, oatmeal, and bacon. But there are similar costs involved in the conversion of raw country-run seeds into the standards of quality now required by agriculture. The purpose of this illustration is not to discredit the services of the manufacturers or their selling prices, but to show how the security of the seed industry is endangered by insufficient gross margins of profit.

My association with the seed trade covers a period just under 30 years. In my early experience "purity" and "germination" were words not generally used in connection with farm seeds. At that time "appearance" was the principal measure of value. It has been a very long step to the present standards of value which are measured by the percentage of purity, weed seed content, inert matter, kind and quantity of noxious weed seeds, percentage of other crop seeds, and the power of growth. Added to these, origin, if domestic, is

verified in cooperation with a department of the government and, if foreign, through identification by staining. Or, in the case of some seeds, the variety is certified and the containers sealed under state authority. Now the costs of these services have added immeasurably to the expenses of doing business. But curiously, these services have been provided almost wholly at the expense of net profits, and the costs have not been transferred to the consumer who has received the benefits. Obviously, adjustments must be made in the method of establishing selling prices to include the cost of raw materials, expenses of operation, and a reasonable profit, plus a safe reserve commensurate with the risks involved and the skill required in the conduct of the business. Very few appreciate the hazards involved in the handling and distribution of farm seeds. The industry has not recovered, nor will it ever recover, the losses sustained by having supplies of seeds available to the consumer in the spring of 1920, unless the adjustments I have mentioned are made effective. Any industry, in order that it may provide the quality of service expected of it, must enjoy a degree of prosperity that will insure its security and enable it to maintain the efficiency of its facilities and increase them in step with new requirements as they may develop. The seed industry is no exception, in fact, the interests of agriculture would be better served were the industry in a stronger financial condition than at present.

At the end of the era of free, or very cheap land, agriculture in all countries has always turned to improved methods to meet the demands of an increasing population. Better farm animals, more efficient equipment, and better seeds have marked a stage in this development here as in the older countries. We have observed the changes which have occurred in the standards of seed quality in less than 30 years as a result of agricultural advancement. In this process we may have developed a standard for which there is no real agricultural demand. Mechanical purities have undoubtedly been over stressed and other qualities under valued. Undoubtedly, some modification will be made in our attitude toward mechanical purity and greater stress laid upon the importance of the weed seed content and less objection made to the presence of small percentages of other crop seeds. Origin and adaptability will become of increasing importance.

A demand is being created for the seeds of the new and improved varieties which have been developed from time to time, and for seed corn best adapted to a given area. Experiments have been made in the distribution of such seeds and these experiments have not always

proved effective or economical. Distribution, to be efficient, must be accomplished at a minimum of waste or of unproductive effort. Obviously, specialized items may be marketed most economically in connection with a general line of kindred products. This holds true of the pure-bred seeds and seed grains you have been developing. The seed trade is in position to accomplish this for you more efficiently and at a lower cost than any other agency. Producers of such seeds often fail to realize that the extravagant values they place upon them prohibit their sale. They desire to wholesale at retail prices to a degree that prevents distribution on a broad scale. Again, it is a matter of education in the value of such seed to the consumer and what may constitute a fair and reasonable return to the producer. After the supply has been built to commercial quantities, the premium to be expected above the value of common varieties must be more clearly understood. Some plan might be formulated to safeguard a reasonable purity of the strain and means provided to protect it through the avenues of distribution from producer to consumer. Reliable, responsible seedsmen may be found in every area of consumption willing and anxious to market pure-bred seeds at a minimum expense and for a reasonable margin of profit.

There is little to be gained by throwing any great and useful machine upon the scrap heap, unless something vastly more efficient is at hand to replace it. In the main, agricultural seeds are being handled efficiently and economically and the existing machinery may be readily adjusted to meet the changing needs of agriculture as they arise. Rather than encourage and support the establishment of new institutions to displace existing agencies, the agricultural workers of the country might more profitably encourage the efficient and progressive seedsmen and assist in the elimination of the weak, inefficient, and undesirable links in the present chain of distribution. We have heard a great deal of the unscrupulous seedsman but no one should expect to find perfection in any industry. A few enemies of agriculture, masquerading as seedsmen, are harmful to the entire industry just as the comparatively few county agents who neglect their real duty to agriculture by dabbling ineffectively in merchandise are harmful to the entire county agent organization. I might also remind you that the unscrupulous seedsman is not supported by the responsible element in the trade, but by the patronage of misguided farmers seeking to purchase seed at prices obviously far below sound established values. Any farmer interested in reliable, dependable seed need not fall victim to the unscrupulous because every county agent, agronomist, or agricultural official is in position to direct him to a dependable source of supply.

The verified origin seed service, just coming into effect, will bring further complications to the seed industry and further increase its over burdened costs of operation. A little more than a year ago foreign and domestic red clover and alfalfa were definitely classified as a result of the staining requirements of the federal Seed Act. The verified origin service will break these commodities up to an extent which may be both unnecessary and wasteful. These seeds are likely to be offered under every single state of growth. Undoubtedly, the needs of agriculture would be best served under a proper territorial grouping of origins. For example, red clover produced in the states of Minnesota, Wisconsin, and Michigan might be properly designated under one area of growth and other states of origin might be similarly grouped. In any event, extensive tests might be undertaken, under the auspices of the American Society of Agronomy, to determine as quickly as possible whether these origins might not be more properly stated in terms of area of growth rather than exact state of origin. This new service will undoubtedly create a demand for information regarding the origin of seed best adapted to a given territory and such information should be made available as soon as possible.

Discussions of the seed trade have not always been tempered by a knowledge of the problems and difficulties which have harrassed it during the evolution through which it has been passing as a result of our agricultural advancement. On behalf of the seed trade generally, I plead for your sympathetic interest in its problems and for your helpful assistance in disposing of them.

The Central Seed Council of North America, just coming into existence, is the expression of the development of a splendid spirit of cooperation between the agencies interested in a dependable seed supply. I express the hope that it will develop into a useful agency through which our common problems may be successfully solved, toward the end that the usefulness of our services may become of increasing value to agriculture in North America.

ELECTRODIALYSIS OF SOILS: II. CHOICE OF ELECTRODES[1]

Harry Humfeld and A. O. Alben[2]

In a previous article (10)[3] some improvements were suggested in the Mattson cell used in the electrodialysis of soils. The results of studies on the time of changing solution and on varying the source of current were given. A means whereby temperature control may be obtained was also described.

Mattson (16) used platinum gauze electrodes in his work. As the cost of these electrodes is considerable, it would seem that if some cheaper material could be substituted for platinum electrodialysis might come into more general use in soil work than would otherwise be the case. The results secured by the use of various substitutes for platinum are given in this paper.

Mention was made in the earlier report of the many uses to which electrodialysis has been put. The apparatus used by the different investigators varied considerably in kind of electrodes, in dialyzing membranes, and in the cell itself. As some of the ideas developed by these workers may be of interest, the various forms of electrodialyzing apparatus used are described herein.

LITERATURE REVIEW

In 1905, Cameron and Bell (3), in their study of the mineral constituents of the soil solution, used electrodialysis as a means of removing the hydrolyzed products. In their studies they worked chiefly with finely powdered minerals, although in one case with a fine sandy loam soil.

Their apparatus, shown in Fig. 1, consisted of two porous cups of unglazed porcelain, one fitted inside the other, and held in place by means of a rubber stopper. The outer cup, about 10 cm high by 45 cm internal diameter, was of the type commonly used in electric batteries. The inner cup was made by cutting off one end of a Pasteur Chamberland filter tube. This cup was fitted with a rubber stopper carrying a block tin tube bent in a gooseneck form above the stopper and pierced with two holes directly below the stopper.

[1]Contribution from the Soil Chemistry and Bacteriological Laboratories, Iowa Agricultural Experiment Station, Ames, Iowa. Received for publication October 7, 1927.

[2]Research Fellows in Soils, Iowa Agricultural Experiment Station. The authors wish to thank Dr. Paul Emerson for helpful suggestions, Dr. P. E. Brown for reading the manuscript, and Dr. N. A. Clark for the use of his laboratory and equipment.

[3]Reference by number is to "Literature Cited," p. 50.

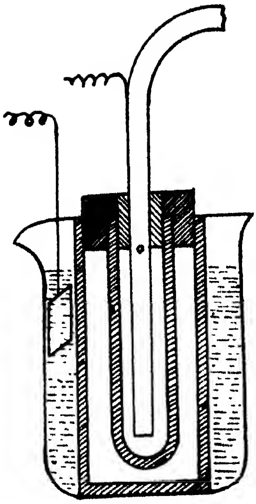

Fig I

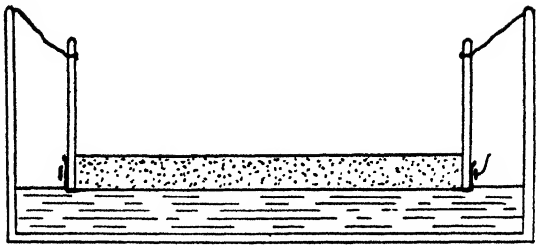

Fig. II

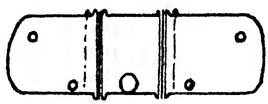

Fig. III a.

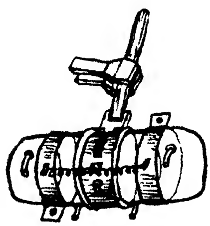

Fig. III b

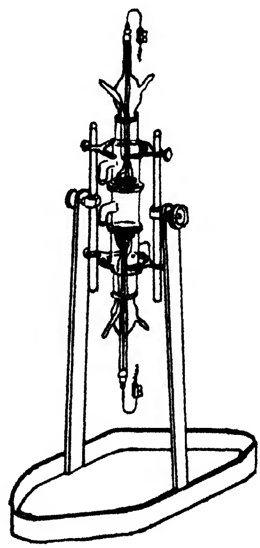

Fig. IV

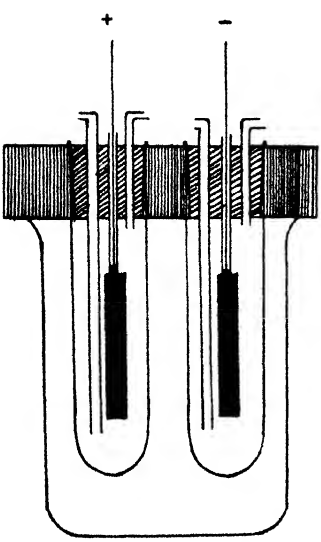

Fig. V

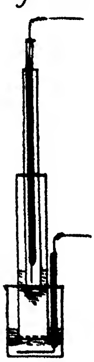

Fig. VI.

These holes were provided to permit the escape and prevent the accumulation of gas in the inner compartment. The whole apparatus was placed in a beaker. The tin tube acted as the cathode and a strip of platinum foil as the anode. The current employed was 40 volts at first with a later increase to 80.

A series of experiments on the effect of an electric current on sludge obtained from water reservoirs was reported by Tillman (20) in 1907. The apparatus is not described, except that a process patented by Count von Schwerin was used. The author was apparently not interested in the composition of the solutions. He considered the fact that he observed a shrinking of the colloidal material as most important and concluded that the method is not suited to the study of this kind of material. For electrodes lead was used as anode and iron as cathode.

In 1911, Konig, Hasenbaumer, and Hassler (12), in an effort to determine the colloids in the soil, made use of the process of electrodialysis. No description of the apparatus was given, except that platinum electrodes were used. They stated that the amount of potassium found in the solution was about the same as can be extracted by hydrogen peroxide, and concluded that the absorption of phosphoric acid depends for the most part on the formation of insoluble calcium phosphate which is not brought into solution again by the action of an electric current. They were of the opinion that the process of electrodialysis can be recommended for the estimation of the soluble nutrients in the soil.

Using electrodialysis in the study of amylase, Lisbonne and Vielquin (14) in 1912 gave no description of their apparatus but stated that a collodion sac was employed for membrane and platinum for the electrodes.

In 1913, Konig, Hasenbaumer, and Glink (11) used the apparatus shown in Fig. 2 for the dialysis of soil and for the determination of its electrical conductivity. Parchment paper was placed underneath the soil, the space between the soil and the bottom receptacle being filled with distilled water. Platinum electrodes were placed at opposite ends of the soil mass. They concluded that the dialysis takes too long a time for the process to be of practical application.

Sheppard, Sweet, and Benedict (18) in 1922 studied gelatin by means of electrodialysis. They used a large wooden cell with outside dimensions of 75 cm long, 51 cm wide, and 50 cm high, Inside of this cell was placed a smaller cell 36.7 by 35.5 by 36.7 cm made of Filtros, a porous silica septum, extending to and cemented to the bottom and sides of the wooden tank. The electrodes used were gold

for the anode, 10.5 by 12.7 cm, and silver for the cathode 25.4 by 25.4 cm. The current used was 110 volts. The capacity of this cell was 48 liters. It is believed that a cell of these dimensions has no application to soil work.

Foster and Schmidt (5) in 1922 used electrodialysis for the separation of the hexone bases from protein hydrolysates. Their cell consisted of a rectangular wooden box, 3 by 6 by 4.5 inches, which was cut into three approximately equal sections. The membranes separating the compartments consisted of strips of linen cloth coated with gelatin and fixed by allowing the strips to remain in formalin overnight. The whole was held together by means of bolts. Asphalt was used to waterproof the wood. Thin sheets of carbon were used for electrodes.

Recently, electrodialysis has been used by a number of investigators for a rather wide variety of purposes.

Freundlich and Loeb (7) used a three-chambered cell, as shown in Fig. 3, for the separation of colloids from crystalloids. The three glass parts were ground to fit exactly on each other and could be fastened to a shaft for support. The center chamber held about 60 cc, although it can be made of any desired capacity. The electrodes were two circular pieces of platinum gauze placed next to the membranes. The membranes were of parchment paper coated with chrome-gelatin. They employed a 12-, a 60- and a 120-volt direct current.

A cell similar to the one just described and shown in Fig. 4 was used by Pauli (17) in his investigations on the water-soluble proteins. The cell was somewhat more complicated, however, as it provides for the passage of a flow of water through the outer chambers during dialysis. Parchment paper or collodion membranes were used The anode was made of platinum gauze, the cathode of silver or iron. The apparatus was assembled in a vertical position and was placed in a horizontal position during operation.

Loche and Hirsch (15) designed an apparatus for the electrodialysis of pseudo globulin. It consisted of two dialyzing thimbles, 16 by 100 mm, the upper end of each being closed with a three-hole rubber stopper. Two tubes were inserted for water circulation. A tube filled with mercury in which was sealed a platinum foil electrode, 1 by 4 cm, was placed in each thimble. The thimbles were mounted in a large cork stopper and placed in a beaker containing the material to be dialyzed. The thimbles were covered with parchment paper to prevent corrosion. Tap water was run continually through the tubes provided for that purpose. The details are shown in Fig. 5.

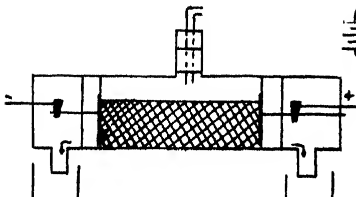

Fig VII

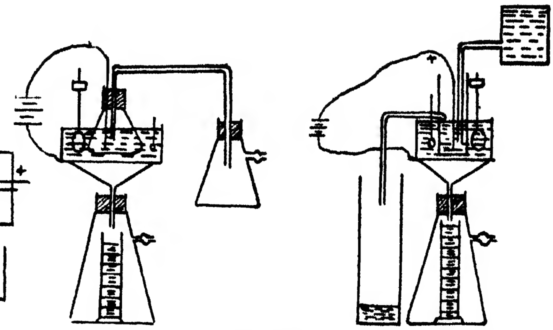

Fig. VIII

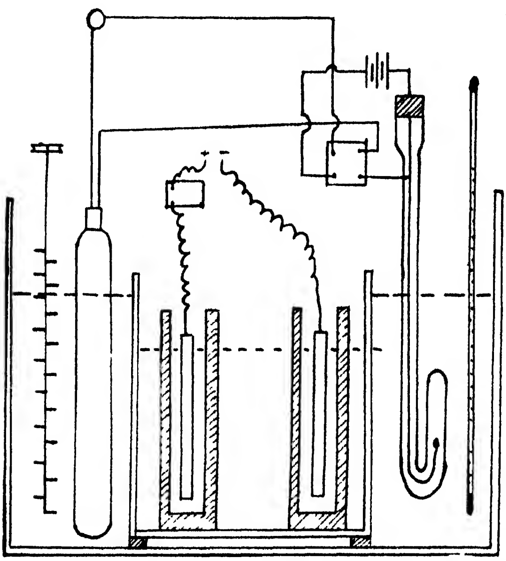

Fig IX

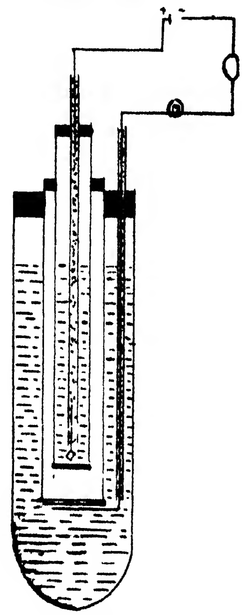

Fig. X

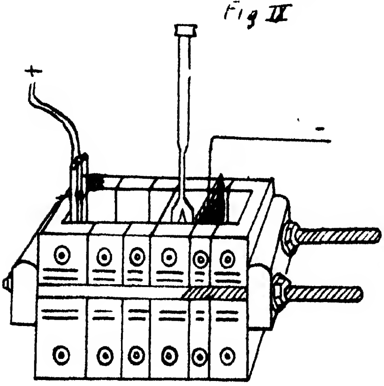

Fig XI

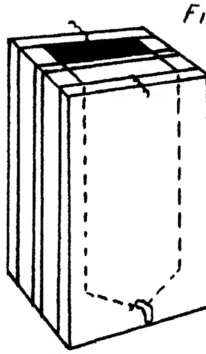

Fig. XII

This method, obviously, would not be adapted to soils as no separation of the dialysate from the tap water is provided.

A continuation of the investigations by Konig, Hasenbaumer, and Hassler (12) was reported by Konig, Hasenbaumer, and Kuppe (13). The apparatus used previously was modified somewhat. It is shown in Fig. 7. Two hundred grams of soil were placed in the cylindrical tube. Cork stoppers were inserted in such a manner that the soil was held in the center. Enough space was left to allow the percolation water to run off. Platinum discs were placed between the cork stoppers and the soil to serve as electrodes. Water was allowed to drip constantly on the water-saturated soil, the runoff being collected in beakers. The current used was 220 volts D. C. If the temperature increased markedly, the voltage was decreased temporarily.

In order to determine the end-point of the solubility action of the electric current, the first two liters of percolate were analyzed together and the third and fourth liters were analyzed separately. Apparently these workers did not consider the possibility of base exchange taking place. They concluded that similar amounts of potassium were brought in solution as were extracted by the hydrogen peroxide method, but that the phosphoric acid extracted varied so much that the method is scarcely applicable to laboratory research in soils.

In 1925, Taylor, Braun, and Scott (19) used the apparatus shown in Fig. 6 for the electrodialysis of insulin. Cloth treated with collodion was used for membrane.

Bechhold and Rosenberg (1) purified gelatin and glue by a process which they called ultrafiltration. The apparatus they used is shown in Fig. 8. The filtration was hastened by the application of an electric current in such a way as to have a tendency to exert a pull through the membrane. The rate of filtration was further increased by the application of suction. The cylinders, made of porous unglazed porcelain, were immersed in the solution. A collodion membrane was used. The anode was of platinum foil or a stick of carbon, while the cathode was of silver-plated metal.

Harvey (8) purified agar by electrodialysis, using the set up shown in Fig. 9. The apparatus included a constant temperature bath in which was placed a large battery jar. The temperature was kept at 50°C. In the battery jar at opposite ends were placed two Electros Filtros cells in which the platinum electrodes were suspended. The agar sol was placed in these cells and sufficient water added almost to cover the electrodes. A 110-volt D. C. current was used.

Hoffman and Gortner (9), also electrodialyzing agar, used a three-compartment box, each compartment of which had a capacity of

1,250 cc. They were separated by heavy sheets of collodion supported by a double layer of white canvas. Carbon plates 12 by 15 cm were used for electrodes. The current was 220 volts D. C.

Bernhard and Beaver (2) in 1926 used the apparatus shown in Fig. 10 for the electrodialysis of human blood serum. The apparatus consisted of three pyrex tubes placed inside each other. The two smallest tubes had a membrane bottom consisting of cotton gauze covered with collodion. The positive electrode was suspended in the center chamber and the negative electrode was placed in the outer chamber. The electrodes were made of platinum foil. The whole apparatus was kept in a constant temperature bath during the process of electrodialysis.

For the purpose of purification of certain ferments, Frische, Fisher, and Barchus (6) used the stoneware cell shown in Fig. 11. The cell consisted of a number of pieces bolted together. The edges were polished and coated with a preparation of paraffin and rubber to make the cell water tight. The membranes used were made of a diaphragm covered with collodion prepared in glacial acetic acid. Chrome-gelatin was also used. A stirrer was placed in the compartment containing the material to be dialyzed. Steel wire was used for the cathode and synthetic graphite for the anode.

Fractionation of serum proteins by means of electrodialysis was reported by Ettish and Beck (4) in 1926. In their work a wool membrane covered with chrome-gelatin was used at the positive side and a parchment membrane on the negative side. The electrodes employed were brass on the cathode and platinum at the anode.

It is believed, however, that for soils work the cell used by Mattson (16), shown in Fig. 12, has the following advantages:

1. The soil layer is comparatively thin.
2. The distance between electrodes is short.
3. The dialysates are separated into acids and bases and can be conveniently collected and saved for analysis.
4. The cell can be taken apart easily for cleaning and changing.
5. The capacity of the center chamber is such that it holds enough soil to give sufficient amounts of bases and acids in the dialysates for quantitative determinations.

This cell was three-chambered, 6 by 8 by 2⅝ inches in size. The outside pieces were of hard rubber, ⅜ inch thick. Between the outside plates were three pieces of U-shaped soft rubber, the center piece being ⅜ inch thick and the other two ¾ inch thick. The whole was held together by a number of bolts. Openings for draining the outer chambers were provided. The membranes were of parch-

ment paper. The electrodes were of platinum gauze, large enough to cover the exposed area of the membranes.

A modified type of this cell as described by the authors (10) in a previous article is the one used in the work reported in this paper. It was found that the rate of dialysis was increased considerably if the ⅜ inch piece of soft rubber in the center was eliminated. If the membranes were placed next to each other, they would bulge enough to hold 100 grams of soil. Reducing the thickness of the layer of soil between the membranes and placing the electrodes so that the distance between them was as short as possible seem to be important factors in increasing the rate of dialysis. With such an arrangement it was necessary to eliminate the cooling system from the center compartment containing the soil, thus depending upon the two outside chambers for temperature control. The only objection to this procedure seems to be that a precipitate tends to form on the glass tube of the cooling system in the chamber containing the cathode. This precipitate consists of a thin whitish deposit, probably mostly calcium, which is rather hard to remove at the end of the dialysis. This condition would have a tendency to make the results obtained for the bases somewhat lower than would otherwise be the case.

EXPERIMENTAL

All the experimental data reported here on the use of different electrodes were obtained with the use of the modified Mattson cell as described. The soil used was a virgin Carrington loam obtained from the Agronomy Farm of the Iowa Agricultural Experiment Station. The solutions in the outer chambers were changed at the successive intervals of 3 hours, 6 hours, 12 hours, 12 hours, and 12 hours. At each change, a record was made of the time, the voltage, the amperage, and the temperature. An effort was made to keep the voltage between 110 and 120.

The electrodes used for the first experiment were two platinum gauze electrodes 4 by 6 inches in size. The results are shown in Table 1.

TABLE 1.—*Results with cathode of platinum gauze and anode of platinum gauze.*

Time in hours	Voltage	Ammeter reading in amperes	Temperature °C	M. E. acids	M. E. bases
3	116	0.67	24	0.453	9.656
9	116	0.21	21	0.175	3.027
21	116	0.21	21	0.185	2.016
33	120	0.10	19	0.134	0.486
45	132	0.10	20	0.103	0.283
			Total	1.050	15.468

In the second experiment a trident-shaped platinum electrode was substituted for the platinum gauze on the basic side, the platinum gauze being retained on the acid side. The results are shown in Table 2.

TABLE 2.—*Results with cathode of three-wire platinum and anode of platinum gauze.*

Time in hours	Voltage	Ammeter reading in amperes	Temperature °C	M. E. acids	M. E. bases
3	106	0.30	19	0.371	6.766
9	106	0.20	21	0.175	3.947
21	106	0.19	19	0.175	2.886
33	125	0.16	20	0.124	1.357
45	125	0.10	19	0.113	0.592
			Totals	0.958	15.548

In the third experiment copper was substituted for platinum on the basic side. It was thought that as no acid is ever present on the cathode side of the membrane during dialysis, copper would not be attacked and could therefore be used. The results of this and subsequent experiments have shown that copper is entirely satisfactory on the basic side. In this experiment a trident-shaped copper-wire electrode was substituted on the basic side for the trident-shaped platinum used in the previous experiment. The results are shown in Table 3.

TABLE 3.—*Results with cathode of three-wire copper and anode of platinum gauze.*

Time in hours	Voltage	Ammeter reading in amperes	Temperature °C	M. E. acids	M. E. bases
3	124	0.70	27	0.453	7.790
9	116	0.20	20	0.144	3.875
21	116	0.30	20	0.154	2.410
33	116	0.12	17	0.103	0.739
45	116	0.05	17	0.062	0.427
			Totals	0.916	15.241

TABLE 4.—*Results with cathode of three-wire copper and anode of three-wire platinum.*

Time in hours	Voltage	Ammeter reading in amperes	Temperature °C	M. E. acids	M. E. bases
3	116	0.56	26	0.206	6.179
9	116	0.25	21	0.206	3.133
21	116	0.28	23	0.268	3.545
33	116	0.20	20	0.206	1.577
45	116	0.18	21	0.175	0.654
			Totals	1.061	15.088

In the fourth experiment the three-wire copper electrode was retained on the basic side. As the three-wire platinum electrode is

less expensive than the platinum gauze, it was thought that it might be possible to substitute the three-wire platinum electrode for the platinum gauze and thus further reduce the cost of the equipment necessary. The results of the experiment with this substitution are shown in Table 4.

In the fifth experiment a piece of copper gauze large enough to cover the inner area of the outer chamber was substituted for the three-wire copper electrode on the basic side. This substitution was found to be very satisfactory, having quite an effect on the rate of dialysis, which will be discussed later. The results of this run are shown in Table 5.

TABLE 5.—*Results with cathode of copper gauze and anode of three-wire platinum.*

Time in hours	Voltage	Ammeter reading in amperes	Temperature °C	M. E. acids	M. E. bases
3	116	0.65	28	0.525	9.523
9	116	0.28	21	0.154	3.545
21	116	0.16	20	0.185	1.555
33	116	0.20	20	0.165	0.499
45	116	0.17	20	0.124	0.314
			Totals	1.153	15.436

In the sixth experiment, the electrodes used were copper gauze on the basic side as used in the previous experiment and platinum gauze on the acid side as used in the first experiment. The results are shown in Table 6.

TABLE 6.—*Results with cathode of copper gauze and anode of platinum gauze.*

Time in hours	Voltage	Ammeter reading in amperes	Temperature °C	M. E. acids	M. E. bases
3	124	1.00	29	0.639	12.654
9	124	0.17	18	0.185	2.067
21	120	0.20	19	0.165	0.561
33	132	0.05	18	0.134	0.239
			Totals	1.123	15.521

DISCUSSION

The various effects produced by the different electrodes described above are brought out very clearly in Fig. 13. It is plainly evident that the use of the copper gauze on the basic side gave the greatest rate of dialysis of any of the combinations tried. The increase in rate over that where platinum gauze was used on both sides is thought to be due to the fact that the copper gauze covered all of the area in the cell, while the platinum gauze, being smaller, did not. This combination seems to be the best available, although a slight

reduction in cost can be secured by the use of a trident-shaped platinum electrode instead of the platinum gauze on the acid side. This substitution slows down the rate somewhat, although not seriously. This latter combination seems to be as effective in removing bases as the two platinum gauze electrodes. The other combinations tried all decreased the rate of dialysis, the combination of a three-wire copper and a three-wire platinum electrode being the slowest.

Fig. 13 also shows very plainly that the end-points all approach the same line and that the total amounts of bases obtained would be the same regardless of which combination of electrodes was used. These and other experiments all show that for any one soil the quantity of bases extracted is very definite and is not affected by the manner of extraction.

If some material could be found which could be substituted for platinum on the acid side, then platinum could be eliminated altogether and the initial cost of an electrodialyzing set up would be materially reduced. A review of the literature revealed that some form of carbon had been used for this purpose. A sheet of carbon ¼ inch thick was obtained from which an electrode was cut which had the same dimensions as the copper gauze described previously. As can be seen from Table 7, the rate of dialysis was very satisfactory and the total amount of bases agreed very closely with the amounts obtained by the use of other electrodes.

TABLE 7.—*Results with cathode of copper gauze and anode of carbon.*

Time in hours	Voltage	Ammeter reading in amperes	Temperature °C	M. E. acids	M. E. bases
3	120	1.80	34	No titration	11.037
9	120	0.75	30	for acid on	3.032
21	115	0.34	22	account	1.155
33	110	0.25	21	turbidity of	0.092
45	115	0.16	20	solutions due to colloidal carbon	0.079
				Total	15.395

However, on the acid side, it was found that the solutions became very turbid, practically black, on account of the decomposition of the carbon under the influence of the electric current. Titration of the acid side was impossible under this condition. The indications are that carbon could be used on the acid side if only base exchange is to be studied. Although the carbon is attacked, an electrode ¼ inch thick would last some time and, as it is comparatively inexpensive, could be easily replaced.

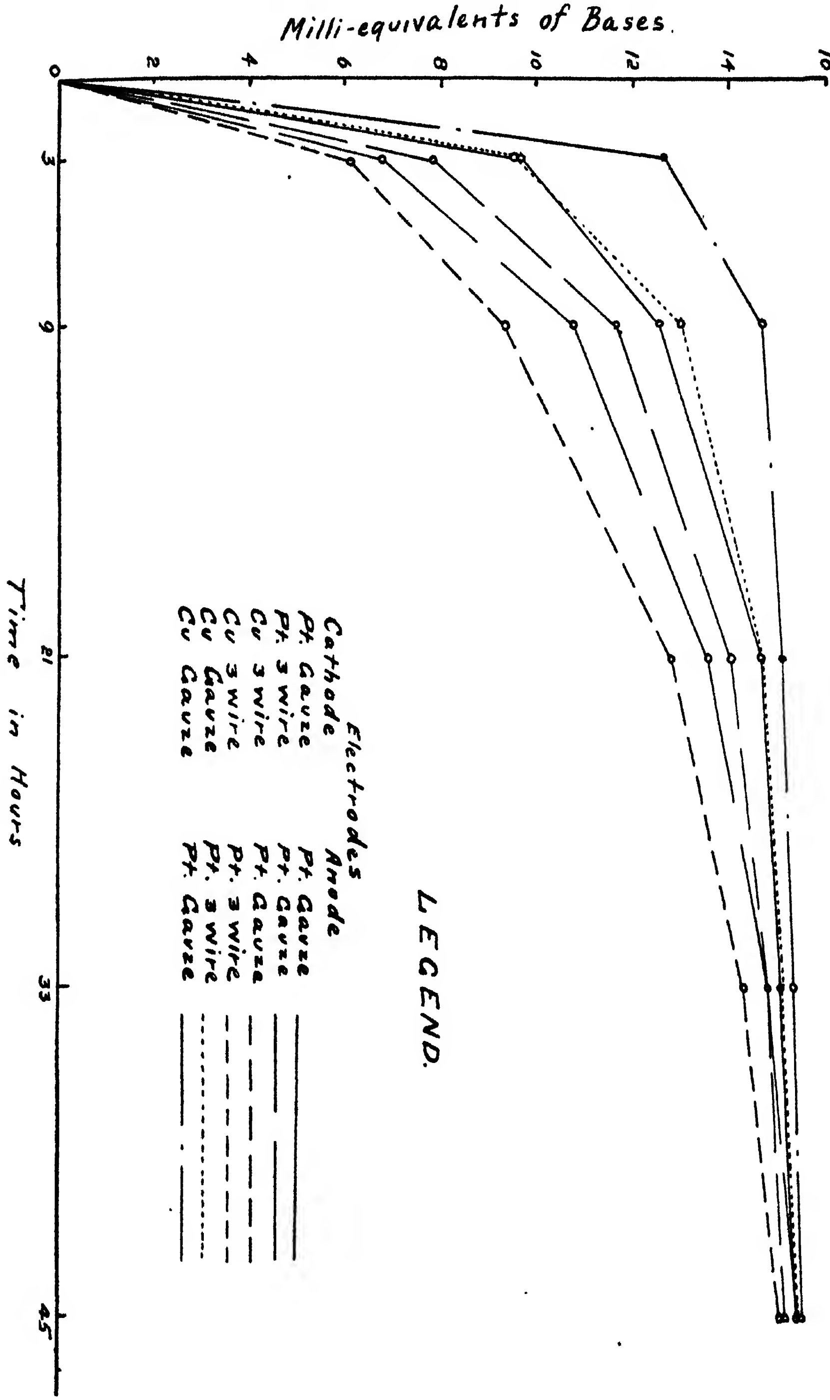
Milli-equivalents of Bases.
0
2
4
6
8
10
12
14
16
3
9
21
33
45
Time in Hours
LEGEND.
Electrodes
Cathode Anode
Pt. Gauze Pt. Gauze
Pt. 3 wire Pt. Gauze
Cu 3 wire Pt. Gauze
Cu 3 wire Pt. 3 wire
Cu Gauze Pt. 3 wire
Cu Gauze Pt. Gauze

Fig XIII.

In correspondence with the research laboratories of the General Electric Company, they suggested the possible use of tungsten or molybdenum in place of platinum. They very kindly furnished tungsten and molybdenum electrodes of the same size as the carbon described in the foregoing. The results for the tungsten are shown in Table 8.

TABLE 8.—*Results with cathode of copper gauze and anode of tungsten.*

Time in hours	Voltage	Ammeter reading in amperes	Temperature °C	M. E. acids	M. E. bases
3	120	0.20	20	0.742	3.828
9	120	0.14	19	0.247	2.316
21	120	0.21	19	0.505	3.076
33	120	0.15	18	0.412	2.294
45	120	0.20	19	0.330	0.973
			Totals	2.236	12.487

It will be seen that in the time allowed, 45 hours, the end-point for the bases was not reached; while on the acid side, the titration was about twice as high as where platinum was used. The electrode was weighed both before and after dialysis and was found to have lost between 0.5 and 0.6 gram in weight. The first change on the acid side was quite turbid, the suspension being yellowish-white in color In all the acid dialysates some sediment was present. No chemical tests were made, but it is known that tungsten will form compounds with acids, phosphoric acid being most active. Although tungsten is almost entirely resistant to acids, it was apparent that under the action of the electric current undesirable reactions took place.

Molybdenum was found to be much more seriously affected. The decomposition was so rapid in this case that the dialysis was abandoned after only a short time as it was evident that the results would be entirely unsatisfactory.

None of the materials used thus far have proved to be satisfactory substitutes for platinum on the acid side.

Mattson (16) used a lamp in series to keep down the temperature inside the cell. The authors (10) substituted a cooling system for this purpose and were able to effect a much more satisfactory temperature control. Increased solubility effects at high temperatures have been surmised, but no data seemed to be available to show whether or not such was a fact. To throw light on this point an experiment was run under the usual conditions, except that the cooling system was eliminated. The results of this experiment are shown in Table 9.

TABLE 9.—*Results with cathode of copper gauze and anode of platinum gauze, without cooling system.*

Time in hours and minutes	Voltage	Ammeter reading in amperes	Temperature °C	M. E. acids	M. E. bases
35 min.	124	1.80	99	0.494	4.710
1 hr. 50 min.	124	1.13	99	0.422	3.555
3 hrs. 10 min.	124	0.80	80	0.268	1.948
5 hrs. 30 min.	124	0.60	81	0.257	1.132
9 hrs.	124	0.50	79	0.226	0.594
21 hrs.	124	1.00	60	1.514	3.602
			Totals	3.181	15.541

The time of changing solutions was rather irregular, due to increase in temperature. The boiling point was reached 35 minutes after the start of the dialysis. The solutions were changed at this time. The second change was made 1 hour and 15 minutes later, at which time the solutions were again boiling. After this change the temperature was high but did not again reach the boiling point.

The titrations show that in spite of the increase in temperature the usual amount of replaceable bases was obtained. However, on the acid side, there seemed to be a considerable increase in solubility, the quantity of acids being approximately three times as great as when the cooling system was used. After all of the replaceable bases had been obtained, continued dialysis might have caused an increase on the basic side as well, due to solubility effects, but the experiment was discontinued after 21 hours as the results showed very plainly the necessity of the use of the cooling system.

SUMMARY

1. A review of the literature reveals that electrodialysis has been used for a number of purposes and that the kind of cells, the membranes, and the electrodes used vary considerably.

2. Results of experiments are given in which different combinations of platinum, copper, carbon, tungsten, and molybdenum are used as electrodes.

3. A copper gauze electrode on the basic side and a platinum gauze electrode on the acid side gave the greatest rate of dialysis.

4. Platinum was found to be the best material for the acid side, while carbon, tungsten, and molybdenum proved to be unsatisfactory.

5. A copper gauze electrode on the basic side and a three-wire platinum electrode on the acid side was the least expensive combination that gave satisfactory results.

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EFFECT OF HAIL INJURY ON THE DEVELOPMENT OF THE CORN PLANT[1]

GEORGE H. DUNGAN[2]

It is difficult to make a correct estimate of the losses to the corn crop as a result of hail injury. Nature does not leave an uninjured check plat to furnish a basis for judging what the yield of grain would have been had there been no hail. Because of this practical difficulty and also for the information on the physiology of the corn plant that such a study would furnish, an investigation of the problem was undertaken. This is a preliminary report of the results obtained.

In view of the fact that natural hail is impossible of control as to time, location, and severity, a form of artificial treatment which injured the plants in a way similar to that of natural hail was employed. The implement used was a wire brush or whip. It was made of 20 pieces of baling wire, 20 inches long, bound into a bundle at one end. This end was used for the handle of a brush formed by the spreading of the wires at the unbound end of the bundle. By striking with this brush in such a way that the burden of the blow was inflicted by the extreme end of the wires a wound partaking of the nature of both a bruise and a tear, greatly resembling that caused by natural hail, was produced upon the blades, partially developed ears, and stalks of corn.

Occasionally, severe hail storms riddle corn blades so completely that their photosynthetic function is practically destroyed. Simulating in an experiment this very destructive action of hail, the blades of some of the plants were jerked off. By giving this treatment to plants at various stages in their development it was possible to learn the influence that the time of the occurrence of the hail storm has on its harmfulness to the corn crop. The data in Table 1 show the effect of what might be termed a moderate and a severe hailing upon the yield of grain.

A moderate hailing as represented by whipping with a wire brush was not nearly as injurious to the yield of corn when it occurred at the time the tassels were emerging as a week later when the ear shoots were emerging. This indicates that the plants are capable of considerable recovery from a hail that injures them comparatively early in their development. With the elongation of the top portion of the plant coincident with tasseling there is a relatively large area of fresh

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TABLE 1.—*Average yield of corn plants artificially hailed at two different stages of development, Urbana, Ill., 1925.*

Date plants were treated	Stage of development of the plants when treated	Treatment	Average yield in bushels per acre of duplicate plats: Treated	Untreated	Difference in favor of untreated plats, bushels
July 18	Tassels emerging on only about one-half the plants	Whipped with wire brush	59.4	62.1	2.7
July 25	All the plants in tassel, ear shoots appearing, but no silks	Whipped with wire brush	52.2	62.1	9.9
July 25	All the plants in tassel, ear shoots appearing, but no silks	Blades jerked off	4.8	62.1	57.3
July 25	All the plants in tassel, ear shoots appearing, but no silks	Blades jerked off and plants whipped with wire brush	3.0	62.1	59.1

leaf surface exposed. This is believed to be the main cause of the rather small reduction in yield when the artificial hail occurred at the time the tips of the tassels were showing on half the plants.

The removal of the blades proved very disastrous. The photosynthetic action of the green stalk and leaf sheaths is evidently not great after the blades have been taken off. There is also very little, if any, grain-forming reserves in the stalk at the beginning of ear shoot development. Seemingly, the elaboration of the materials entering into the developing ear immediately precedes their translocation to the ear.

The bruising and tearing action of the wire brush following the stripping of the blades reduced the yield to the extent of 1.8 bushels an acre or 37.5%. The bruising of the stalks and ears is one of the important injuries caused by hail. This type of injury would probably tend to increase in severity as the corn plants develop, at least, up to the soft dough stage.

The amount of injury produced is influenced by the stage of the development of the plant. With a light artificial hailing the reduction in yield was 2.7 bushels an acre when the plants were tasseling as compared to 9.9 bushels when the ear shoots were emerging. In order to see what the effect would be of treatments applied still later in the development of the plants a second series of tests were made. The treatment consisted of removing the blades from the plants at five different stages of development, ranging from the early silk to the soft dough stage. The data showing reduction of yield due to the treatment are presented in Table 2.

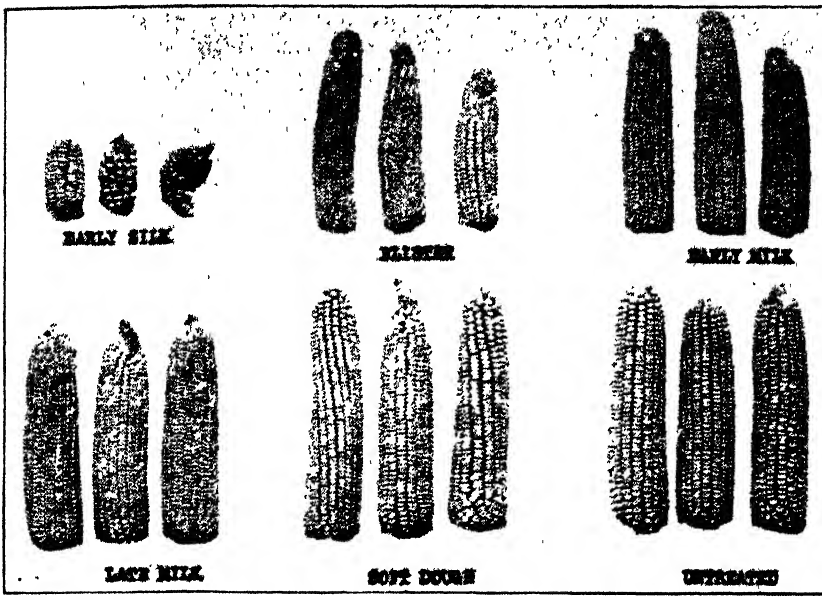

FIG. 1.—Three representative ears of corn from plants treated by stripping the blades at different stages of development, namely, early silk stage, blister stage, early milk stage, late milk stage, and soft dough stage, as compared with three ears from plants the blades of which were not removed.

TABLE 2.—*Average yield of corn plants from which the blades were removed at five different stages of development, Urbana, Ill., 1926.*

Date blades were removed	Stage of development of the plants when treated	Average yield in bushels per acre of two treated plats	Average yield in bushels per acre of adjacent untreated plats	Difference in favor of untreated plats in bushels
Aug. 16	All plants in tassel, some beginning to silk	1.3	28.9	27.6
Aug. 26	Grain in the blister stage	7.8	29.1	21.3
Sept. 6	Grain in the early milk stage	14.0	30.8	16.8
Sept. 16	Grain in the late milk stage	22.2	30.2	8.0
Sept. 26	Grain in the soft dough or glaze stage, frost occurred the night before	29.4	35.4	6.0

The reduction in yield resulting from the treatment was progressively less as the corn approached maturity. There was a 6-bushel decrease caused by stripping the blades the next day after the frost. Only the upper blades and tips and edges of the lower ones were killed by the frost, indicating the possibility of considerable elaboration of materials after the frost. It is believed, however, that

the larger part of the benefit derived by allowing the blades to remain on the plants was due to the uninterrupted translocation to the ear of materials elaborated by the leaves before the frost.

The ears represented in Fig. 1 were selected to show the effect of the treatment upon the type of ear and grain. When the blades were removed in the early silk stage, the plants were able to adjust themselves to their reduced photosynthetic area in time to permit the formation of a very small ear and the development of a practically normal type horny grain. The cobs and grains on the plants treated later had developed so far when the blades were stripped that the effect of the treatment was shown primarily in the lack of plumpness and in the floury or chaffy character of the grain. As the treatment was delayed the grain was progressively better filled and more horny in character.

SUMMARY

Corn plants were treated experimentally in such a manner as to simulate the injury of hail. A light treatment inflicted at the time the tassels were just emerging reduced the yield of grain only 2.7 bushels an acre. One week later when the plants were in tassel and ear-shoots, but no silks were showing, an artificial hail treatment of the same severity reduced the yield 9.9 bushels an acre.

A severe hail storm, represented in this experiment by jerking off the blades, was very destructive to corn yields, especially when it occurred at the early silk stage of the plant. Applications of this same treatment at later periods in the growth of the corn plant produced a less damaging effect, and the reduction in yield was progressively less as the treatment was administered later in the plant's development.

THE AVAILABILITY OF POTASSIUM TO PLANTS AS AFFECTED BY BARNYARD MANURE[1]

R. P. BARTHOLOMEW[2]

The importance of farm manure in maintaining soil fertility in the present system of agriculture cannot be over emphasized. Manure supplies nitrogen, phosphorus, potassium, and calcium and a large amount of organic matter to the soil. The value of manure as a carrier of nitrogen and phosphorus has been determined by a large number of experiments. The conclusions drawn from the few experiments on manure as a carrier of potassium, because of their contradictory nature, suggest a lack of understanding with regard, first, to the availability of the potassium in manure, and second, to the effect of the manure in converting the insoluble potassium minerals in the soil into salts which can be used by the plants.

Manure contains potassium which is directly available to plants and it may also react on the soil so as to make the insoluble and relatively unavailable potassium of the soil more soluble and more available for plant growth. This investigation was undertaken to study the rate of availability of the potassium in manure itself and also to determine, if possible, any effect the manure may have on the soil to make the inert potassium of the soil more available.

TABLE 1.—*Percentage of K in cow manure.*

Sample No.	H_2SO_4 ignition	HCl extraction	$N/5$ HNO_3 extraction	H_2O extraction	H_2O soluble[a]
1	2.734	2.806	——	2.760	98.0
2	1.603	1.650	——	1.391	84.2
3	1.179	1.257	——	0.986	78.4
4	1.040	1.095	1.110	1.002	91.5

[a]HCl extraction which gave the highest amount of total K was taken as 100%.

AVAILABILITY OF POTASSIUM IN MANURE

Most of the potassium in manure is in a soluble form. Chemical analyses made by the writer and reported in Table 1 show that all the potassium can be extracted from manure by strong HCl or $N/5$ HNO_3, indicating that all the potassium may be available long before the organic matter of the manure is completely decomposed.

[1]Part of a thesis submitted to the faculty of the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with the permission of the Director of the Wisconsin Experiment Station. Received for publication October 8, 1927.

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Furthermore, most of the potassium is in a water-soluble form as shown by water extractions of manure samples.

Hall (7)[3] and Stoklassa (17) show that potassium is intimately related to carbohydrate synthesis in plants. However, they do not state in what form the potassium exists in plants. All the data known to the writer show that potassium is present in plants as salts. These salts, with few exceptions, such as potassium acid tartrate in grapes, are very soluble in water.

During the process of digestion in animals, most of the potassium would be dissolved and eliminated in the liquid excreta. A small amount of potassium would be present in the solid excreta, probably due to occlusion by the solid material. This is in accord with data presented by Hall (8) showing that in cow manure 0.04% K_2O is contained in the solid excreta and 1.36% in the liquid excreta.

The fact that the potassium in manure is so soluble suggests that the method of handling the manure will be a large factor in determining the amount which it will contain. However, that is not the only factor affecting the amount of potassium in manure. Hart (9) and Fippin (6) have shown that the feeds and litter used may affect the potassium content of manure. The type and age of the animals are other factors which affect the potassium content of manure according to data from Hall (8) and Bunge (4, 5).

It is not the purpose of this paper to discuss methods of handling manure and it will suffice to point out that any method is wasteful which does not consider the saving of the liquid excreta and the prevention of leaching by rain of the soluble plant foods from the manure.

In order to determine the amount of leaching which might be possible under Wisconsin conditions during the months of January, February, and March, a weighed sample of manure was packed in a galvanized iron cylinder and leached with an amount of water corresponding to the average precipitation, 6.13 inches, for those three months. The water was sprayed on in 15 applications over a period of two days and the leachings were analyzed for potassium. A sample of unleached and leached manure was also analyzed. The results are given in Table 2.

TABLE 2.—*Loss of K from manure by leaching.*

Sample	H_2O	N in dry matter	P in dry matter	K in dry matter
	%	%	%	%
Unleached.......	81.6	2.58	0.624	1.603
Leached.........	84.1	2.49	0.628	1.154

[3]Reference by number is to "Literature Cited," p. 80.

The amount of potassium in the leachings indicates a loss of 0.49% K by leaching. This figure checks very closely with the loss of K as found by analysis of the solid matter. While this loss is large, amounting to approximately 20% of the total potassium, it is very probable that it is not nearly as large as would occur under normal barnyard conditions. Under barnyard conditions the amount of precipitation coming at one time is probably only a fraction of that applied in this experiment. That condition is favorable for greater leaching as it enables the liquid in the manure to become saturated with potassium before it leaches out.

It has been generally accepted that a ton of average manure contains 10 pounds of nitrogen, 2 pounds of phosphorus, and 8 pounds of potassium. These are extremely general figures, particularly with regard to the amount of potassium, and have no practical or scientific value as the manures containing those amounts of fertilizing elements are the exception rather than the rule. The actual amounts

TABLE 3.—*Composition of cow manure from Wisconsin branch experiment stations.*

Station and Sample No.		H_2O %	K in dry matter %	Station and Sample No.		H_2O %	K in dry matter %
Ashland	1	83.2	2.67				
Ashland	2	81.7	2.895	Marshfield	2	80.56	1.92
Ashland	3		2.501	Marshfield	3	76.0	2.61
				Marshfield	4	84.5	2.13
Spooner	1	81.0	2.966	Marshfield	5	80.35	2.25
Spooner	2	78.67	2.83	Marshfield	6	86.68	2.08
Spooner	3	70.94	2.224	Marshfield	7	83.5	2.28
Spooner	4	80.92	2.650	Marshfield	8	82.12	1.35
Spooner	5	77.71	2.534	Marshfield	9	80.56	2.68
Spooner	6	79.7	2.250	Marshfield	10	84.52	2.50
Spooner	7	78.08	2.261	Marshfield	11	80.0	1.36
Spooner	8	77.73	2.161	Marshfield	12	83.96	1.72
Spooner	9	78.9	1.841	Marshfield	13	81.76	1.67
Spooner	10	82.77	1.605				
Spooner	11	82.26	1.88	Hancock	4	70.7	0.516
Spooner	12	80.53	2.11	Hancock	5	74.4	0.944
Spooner	13	87.22	2.52	Hancock	6	75.8	1.045
Spooner	14	81.57	1.67	Hancock	7	68.8	0.723
Spooner	15	83.64	1.78	Hancock	8	81.36	0.870
Spooner	16		2.50				
Spooner	17	75.00	1.70				
Spooner	18	80.26	2.52	Coddington	1	77.4	1.188
Spooner	19	77.1	2.22	Coddington	2	82.00	1.144
Spooner	20	80.56	2.83				
				Madison	1	63.4	2.734
				Madison	2	81.6	1.603
Marshfield	1	80.00	1.934	Madison	3	84.14	1.154

are usually either above or below those figures. Analyses (Table 3) made by the writer upon samples of manure secured from the Wisconsin branch experiment stations and from farms located within a few miles of the branch stations show that the amount of potassium in manures varies greatly.

Data compiled by Thorne and Hickman (18) indicate that the potassium may vary from 2.8 pounds to 17 pounds per ton of manure. Lindsey, et al (10) report for 60 samples figures that vary between the limits reported by Thorne and Hickman. The data show that the potassium in the manure produced by the same herd may vary from 5 to 12 pounds per ton. This variation may be due to any one or more of the factors mentioned above. While the difference in some cases may seem small, the total amount of potassium that would be applied in the usual applications of manure would vary greatly. For example, a difference of only 0.2% of K in two manures having the same moisture content would mean a variation of 0.8 pound of potassium per ton of manure, or a difference of 8 pounds of soluble potassium per acre in an application of 10 tons of manure. This is sufficient available potassium to cause quite a marked difference in crop growth.

The question of availability becomes more complex after the manure has been applied to the soil. There are several factors which may affect the amount of potassium available from the manure for plant growth. Obviously, the first and most important factor is the fixation of potassium by the soil. Another factor, as shown by the work of Ames and Simon (2), is the removal of the added potassium from the surface layer to the subsurface and subsoil where it is fixed. There is also a possibility that some potassium may be leached out in the drainage water if a soil is very sandy or the layer underlying a heavy surface soil is very gravelly or sandy. It is probably true that these factors exert some influence under field conditions, but as will be seen from data to be presented later in this paper, they probably affect only a small amount of the potassium that is added to the soil.

The results given below from field experiments are very contradictory. This would be expected, due to the fact that meteorological factors which cannot be controlled may become limiting factors in plant growth. Wagner (19) reports from a series of 18 different field experiments located in various parts of Germany a variation of 7.4% to 85.0% in the recovery of potassium from manure. He determined the amount of potassium removed from the unfertilized plats and subtracted that amount from the total amount removed by the

plants where manure was applied. The remainder he considered as potassium recovered from the manure.

Schulze (14) and Schneidewind (13) secured similar results from plats with fertilizer treatments similar to those of Wagner.

Brooks, Fulton, and Gaskill (3) report that not over 60% of the potassium applied every three years in six cords of manure was recovered during a period of 16 years.

Data published by Thorne and Hickman (18) and Ames and Gaither (1) show increased yields from supplementing manure with kainite.

Soule and Vanatter (15) secured an increase of 12 bushels of potatoes when they supplemented 15 tons of manure with 100 pounds of potassium sulfate.

Stevenson (16) secured a lower yield of corn and oats when he added 100 pounds of potassium chloride to the manure than from manure alone.

The question of the availability of potassium in manure is well adapted for the study in the green house because meteorological variations, such as temperature and moisture, can be controlled and potassium can be made the factor limiting plant growth. By this method, quantitative results can be obtained which would indicate the results that might be expected under favorable field conditions.

PLAN OF EXPERIMENT

It seems plausible that more consistent results would be obtained if the supply of potassium were the only factor limiting plant growth. To determine if this is true, a series of experiments were started in 1924 and continued on the same general plan in 1925 and 1926. The plan of the experiments was to grow alfalfa, which feeds heavily upon potassium, and oats and Sudan grass which do not require such large amounts of potassium for normal growth, in quartz sand and in soils with manure and various combinations of mineral fertilizers and manure plus mineral fertilizers. All crops were grown at the rate of 12 plants per jar.

The plants were grown in 2-gallon jars having holes at the bottom for drainage and containing the same weight of soil or sand to a series. Lime was applied at the rate necessary to correct the acidity as shown by the Truog test. Manure was chopped as fine as possible and mixed thoroughly by hand with the soil in the amounts given in the tables accompanying the experiments. Nitrogen, phosphorus, and potassium, when added, were applied in water solution as sodium nitrate, monocalcium phosphate, and potassium chloride. Hereafter in this paper the symbols N, P, and K, respectively, will be used

to designate those salts. They were sprinkled on the soil and mixed thoroughly by rubbing between the hands. The moisture was maintained as near the optimum as possible. All quartz cultures received suspensions made from neutral soils. The alfalfa plants were inoculated by watering them when they were about a half an inch high with a suspension of alfalfa bacteria. Analyses were made on the manures used and on some of the plant tissue harvested. Analyses for potassium were made only on plants from jars from which one would expect the largest amount of potassium to be taken from the soil alone or from the soil plus manure.

1924 EXPERIMENTS

Oats followed by Sudan grass was grown in quartz cultures receiving different fertilizer treatments. The treatments and yields are given in Table 4.

Plant growth alone gives no index to the amount of the plant food elements taken up by the plant, so analyses were made of the manure to see how much potassium was added to the soil and of the mature plant tissue to see how much potassium was recovered by the plant. The manure contained 2.72% potassium on the dry basis. The results of the plant analyses are given in Table 5.

TABLE 4.—*Yields on quartz sand of oats followed by Sudan grass, 1924.*

Jar No.	Fertilizer treatments, pounds or tons per acre	Average air-dry weight in grams of oats straw and grain	Average total air-dry weight in grams of Sudan grass hay
17–18	None	1.20	0.45
19–20	8 M[a]	10.13	7.30
21–22	16 M	10.49	17.88
23–24	8 M, 50 N, 100 P	9.45	6.55
25–26	16 M, 50 N, 100 P	13.05	17.50

[a]The symbol M, wherever used in this paper, designates manure.

TABLE 5.—*Amount of K recovered from manure by oats followed by Sudan grass grown in quartz sand, 1924.*

	Jar number 23	24	25	26
K in air-dry oat tops, %	4.090	4.185	4.316	4.183
K in air-dry oat roots, %	0.638	0.638	0.638	0.638
K in air-dry grass tops, %	1.482	1.509	2.482	2.681
K in air-dry grass roots, %	0.580	0.580	0.580	0.580
Mgs K recovered in oat tops	395.9	385.5	536.0	572.2
Mgs K recovered in oat roots	15.2	14.7	19.8	21.8
Mgs K recovered in grass tops	150.9	174.3	435.2	467.9
Mgs K recovered in grass roots	11.8	13.5	33.9	33.7
Total mgs K recovered	573.8	588.0	1,024.9	1,095.6
Mgs added in manure	613.0	613.0	1,226.0	1,226.0
K recovered, %	93.6	95.5	83.7	89.3

TABLE 6.—*Total yield of alfalfa hay on quartz sand, 1924.*

Jar No.	Fertilizer treatment in pounds or tons per acre	Grams of dry alfalfa hay, average of 2 jars
39–40	None	0.25
41–42	8 M	38.76
43–44	16 M	40.67
45–46	8 M, 50 N, 100 P	38.68
47–48	16 M, 50 N, 100 P	44.13

TABLE 7.—*Amount of K recovered from manure by alfalfa grown on quartz sand, 1924.*

	Average of jars 45–46	Average of jars 47–48
K in air-dry alfalfa hay, %......	1.636	2.875
K in air-dry alfalfa roots, %.....	0.386	0.386
Mgs K recovered in alfalfa hay...	645.6	1,263.1
Mgs K recovered in alfalfa roots..	49.7	56.8
Total mgs K recovered..........	695.3	1,319.9
Mgs added in manure...........	613.0	1,226.0
K recovered, %................	113.0	107.6

Alfalfa was seeded in quartz cultures February 25 and cuttings were made when the plants were in the same stage of maturity on May 29, July 8, August 28, October 1, October 29, and December 15. The fertilizer treatments and yields are given in Table 6. The amounts of potassium recovered from the manure are found in Table 7.

The figures given for the roots are very general and were obtained by washing the roots from a number of jars and obtaining the average ratio of the weight of the roots to the weight of the tops. The factor used for oats was one-fourth the weight of the tops and that for Sudan grass and alfalfa was one-third the weight of the tops. All of each species were ground in composite samples and analyzed for K. The results of the analyses are as follows: Alfalfa, 0.386% K; Sudan grass, 0.58% K; and oats, 0.638% K.

The results of the analyses recorded in Tables 5 and 7 indicate that most of the potassium can be recovered from the manure by growing plants. A comparison of the analyses of the oats, Sudan grass, and alfalfa plants seems to indicate that when there is a large amount of available potassium present it will be taken up to the maximum capacity of the plant, but that when the supply of available potassium becomes deficient the growth of the plant will be retarded and the percentage of potassium in the plant lowered. For example, twice as much potassium was taken up from jars 47–48 as from jars 45–46 and yet there was only a 12 % greater yield of dry hay. While the length of time used in growing the crops in this and future experiments is sometimes greater than under field conditions, it does not detract from the significance of the results as the experiments were

planned to see if the potassium in the manure remained available for plant growth over a long period of time.

ALFALFA IN SOIL

Alfalfa was seeded February 25 in silty clay loam soil and cuttings made on the dates given in the preceding experiment. The yields and the amounts of potassium recovered from the manure are given in Table 8.

TABLE 8.—*K recovered from manure by alfalfa grown in sand and soil mixture, 1924.*

Jar No.	Fertilizer treatment in pounds or tons per acre	Yield in grams air-dry alfalfa hay	K in air-dry tissue %	Mgs K taken up by plant tops and roots	K recovered from manure %
9–10	100 N, 200 P	41.30	1.015	459.2	——
11–12	12 M	51.72	——	——	——
13–14	12 M, 100 N, 200 P	60.15	1.946	1,224.2	83.75
15–16	100 N, 200 P, 100 K	43.51	——	——	——

The percentage recovery was obtained by subtracting the K recovered from jars 9–10 from that recovered from jars 13–14 and the remainder divided by 919, the amount added in the manure.

The results indicate that a large percentage of the potassium in manures is available for plant growth. The results represent the minimum amounts of potassium which were taken from the manure. The potassium content of the plants, where manure was added, was twice as great as where only nitrogen and phosphorus were added. This indicates that there was an abundant supply of available potassium and that alfalfa plants, where manure was added, were not feeding to their maximum capacity on the potassium from the soil. This contention is further supported by the fact that a 50% increase in dry weight of alfalfa hay took up almost three times as much potassium.

1925 EXPERIMENTS

The plan of the experiments for 1925 was practically the same as in the previous experiments. Mineral fertilizers were applied to the soils in such combinations as would indicate whether the soils were deficient in available potassium. This favored an accurate study of the action of the potassium applied in the manure.

The crops were all harvested in the same stages of maturity, which for the various crops were as follows: Oats, when the grain was ripe; Sudan grass, after seed had formed but not ripened; alfalfa, cut in the early bloom stage. Analyses were not made on plant tissue from all the experiments but only from occasional experiments to see if the results were consistent with those obtained the previous year.

ALFALFA ON QUARTZ SAND

Alfalfa was planted on February 21, in jars containing 11 kgms of quartz sand and various fertilizers. Five cuttings were made, on May 23, June 22, August 1, September 4, and October 25. The fertilizer treatments, yields, and amounts of K recovered from the manure are given in Table 9.

The results agree with those obtained in 1924 in showing that practically all the potassium in the manure is available for plant growth and that when there is a large supply of available potassium the percentage of potassium in the plant will be considerably larger than when the supply of available potassium is small.

TABLE 9.—*Yield and amount of K recovered from manure by alfalfa grown on quartz sand, 1925.*

Jar No.	Treatment in pounds or tons per acre	Average yield in grams air-dry alfalfa hay	K in alfalfa hay %	Mgs K taken up by plant tops and roots	K recovered from manure %
4	8 M	19.97[a]	——	——	——
6	16 M	24.79[a]	1.315	359.7	100
7–8	8 M, 50 N, 100 P	22.00	0.818	197.2	109
9–10	16 M, 50 N, 100 P	24.56	1.502	395.2	109
11–12	8 M, 100 P, 50 K	23.68	——	——	——
13–14	16 M, 100 P, 50 K	29.73	——	——	——

[a]Weight of one jar only.

GROWTH OF CROPS ON PLAINFIELD SAND

The sand was secured from the experimental farm at Hancook, Wisconsin, and as far as is known it has never received any fertilizer treatment. It was in a low state of fertility as it contained only 0.040% nitrogen, 0.023% phosphorus, and 0.667% potassium. Alfalfa, oats, and Sudan grass were grown in the same manner as described for previous experiments. The results are given in Tables 10, 11, and 12.

TABLE 10.—*Yield and amount of K recovered from manure by alfalfa grown on Plainfield sand, 1925.*

Jar No.	Fertilizer treatment in pounds or tons per acre	Average yield in grams air-dry alfalfa hay	K in alfalfa hay %	Mgs K taken up by plant tops and roots	K recovered from manure %
133–4	None	23.15	——	——	——
135–6	100 N, 200 P	26.15	0.878	264.4	——
137–8	100 N, 200 P, 100 K	30.77	——	——	——
139–40	12 M	39.88	——	——	——
141–2	12 M, 100 N, 200 P	40.01	1.267	555.2	107
143–4	12 M, 100 N, 200 K	44.03	——	——	——

A study of the yields of alfalfa, oats, and Sudan grass hay with the various fertilizer treatments indicates that there is a deficiency of available potassium in the soil, for in nearly all cases where potassium was added in the fertilizer, there was an increase in yield. This being the case, the plants should feed upon the potassium in the manure to the maximum extent of its availability. The results show that practically all the potassium in manure is available for plant growth.

TABLE 11.—*Yield and amount of K recovered from manure by oats grown on Plainfield sand, 1925.*

Jar No.	Fertilizer treatment in pounds or tons per acre	Average yield of straw and chaff in grams	Average yield of grain in grams	K in whole plant (grain and straw) %	Mgs K taken up by tops and roots	K recovered from manure %
145-6	None	6.69	1.84	—	—	—
147-8	100 N, 200 P	12.48	2.77	0.809	141.3	—
149-50	100 N, 200 P, 100 K	13.15	3.60	—	—	—
151-2	12 M	12.90	2.44	—	—	—
153-4	12 M, 100 N, 200 P	15.93	5.84	1.59	381.3	88.8
155-6	12 M, 100 N, 200 P, 100 K	18.09	8.12	—	—	—

TABLE 12.—*Yield and amount of K recovered from manure by Sudan grass grown on Plainfield sand, 1925.*

Jar No.	Fertilizer treatment in pounds or tons per acre	Average total yield in grams air-dry hay	K in Sudan grass hay %	Mgs K taken up by tops and roots	K recovered from manure %
157-8	None	12.87	—	—	—
159-60	100 N, 200 P	17.97	0.707	161.4	—
161-2	100 N, 200 P, 100 K	17.61	—	—	—
163-4	12 M	26.51	—	—	—
165-6	12 M, 100 N, 200 P	27.60	1.384	433.8	100.7
167-8	12 M, 100 N, 200 P, 100 K	27.45	—	—	—

GROWTH OF CROPS ON MIAMI SILT LOAM

This soil was derived from glaciated limestone material and is of a light brown color. The soil was obtained from a series of check plats from the Isom Field at Madison, Wisconsin. As far as is known there has been no fertilizer applied in the last 38 years. The soil contains 0.107% nitrogen, 0.035% phosphorus, and 1.718% potassium.

TABLE 13.—*Yield and amount of K recovered from manure by alfalfa grown on Miami silt loam, 1925.*

Jar No.	Treatment in pounds or tons per acre	Average total yield of air-dry alfalfa hay in grams	K in alfalfa hay %	Mgs K taken up by plants (tops and roots)	K recovered from manure %
	None	17.96[a]	——	——	——
289–0	100 N, 200 P	31.17	0.928	324.0	——
	100 N, 200 P, 100 K	33.88[a]	——	——	——
293–4	12 M	33.46	——	——	——
295–6	12 M, 100 N, 200 P	38.15	1.314	554.5	85.1
297–8	12 M, 100 N, 200 P, 100 K	40.04	——	——	——
299–0	12 M, 100 N, 200 P, 300 K	42.31	——	——	——

[a]Average of 4 jars.

Alfalfa, oats, and Sudan grass were grown in jars containing 7.5 kgms of soil and various fertilizers. Analyses were made on some

TABLE 14.—*Yields and amounts of K recovered from manure by oats grown on Miami silt loam, 1925.*

Jar No.	Treatment in pounds or tons per acre	Average yield of grain in grams	Average yield of straw and chaff in grams	K in oat tops (grain and straw) %	Mgs K taken up by plants (tops and roots)	K recovered from manure %
	None	3.72[a]	11.30[a]	——	——	——
265–6	100 N, 200 P	11.75	19.15	1.014	362.0	——
	100 N, 200 P, 100 K	10.04[a]	20.10[a]	——	——	——
269–0	12 M	9.20	18.73	——	——	——
271–2	12 M, 100 N, 200 P	12.75	22.23	1.393	543.8	66.3
273–4	12 M, 100 N, 200 P, 100 K	11.67	22.75	——	——	——

[a]Average of 4 jars.

TABLE 15.—*Yield and amount of K recovered from manure by Sudan grass grown on Miami silt loam, 1925.*

Jar No.	Treatment in pounds or tons per acre	Average total yield of air-dry Sudan grass in grams	K in Sudan grass %	Mgs K taken up by plant (tops and roots)	K recovered from manure %
	None	20.29[a]	——	——	——
241–2	100 N, 200 P	35.10	0.800	357.6	——
	100 N, 200 P, 100 K	39.36[a]	——	——	——
245–6	12 M	40.93	——	——	——
247–8	12 M, 100 N, 200 P	43.28	0.964	500.9	53.0
249–0	12 M, 100 N, 200 P, 100 K	44.99	——	——	——

[a]Average of 4 jars.

of the plants from several jars in order to determine the amount of potassium recovered by plants from the manure. The results are given in Tables 13, 14, and 15.

Even with a large supply of available potassium in the soil much of that added in the manure was recovered by plant growth. Alfalfa which is a heavy feeder on potassium recovered 85.1% of the potassium in the manure, oats recovered 66.3%, and Sudan grass recovered 53%. It is very probable that more of the potassium added in the manure was recovered than is shown by the percentages given above. It is very improbable that the plants would remove all the potassium that is available from the soil before using the potassium available from the manure. However, there is no means of separating the potassium used by the plants from the different sources.

The analyses of the plant tissue show that the highest percentages of potassium are found in those plants grown in jars receiving applications of available potassium. These results are in accord with those found in previous experiments.

Similar results were obtained in 1926 on Colby silt loam, Plainfield sand, Carrington silt loam, Miami silt loam, Marathon silt loam, peat, Superior clay loam, and a Plainfield sand which contained so many granitic particles that it was almost a Vilas sand.

FIELD EXPERIMENTS

Experiments were started at the Marshfield Branch Experiment Station to see if results obtained in the plant house could be duplicated under field conditions.

The experiments at Marshfield were planned on the assumption that crops had removed from the soil practically all the available potassium added in previous manure applications. If the assumption was true, the application of potassium fertilizers should cause marked increases in growth.

The experiments were conducted on Colby silt loam soil on one-third acre plats which have been used for drainage studies since 1915. A six-year rotation of corn, barley, alfalfa three years, and potatoes is used. Ten tons of manure and 600 pounds of acid phosphate have been applied once in a rotation. Manure was applied half on corn and half on potatoes, while the acid phosphate was applied at the rate of 200 pounds each on corn, barley, and potatoes.

The rotation was altered somewhat in 1923 by leaving several stands of alfalfa which ordinarily would have been turned under in order to get sufficient hay for the needs of the Experiment Station.

TABLE 16.—*Yield of alfalfa hay on Colby silt loam at Marshfield, 1925.*

	Plat number and age of stand									
	1200, 5 years		1300, 4 years		1400, 3 years		900, 2 years		1000, 1 year	
Fertilizer treatment for this experiment	None	100 pounds KCl[a]	None	100 pounds KCl	None	100 pounds KCl	None	100 pounds KCl	None	100 pounds KCl
Average dry weight, %[b]	16.7	16.7	19.85	19.85	19.7	19.7	20.7	20.7	18.8	18.8
Yield of 6 square yards, pounds green weight	22.6	23.8	15.4	17.0	8.3	10.5	11.1	13.1	24.0	28.5
Yield 6 square yards, pounds dry weight	3.77	3.97	3.05	3.37	1.63	2.06	2.29	2.71	4.51	5.35
Tons dry hay per acre	1.520	1.602	1.233	1.361	0.659	0.835	0.927	1.094	3.056[c]	3.542[c]
Increase due to K, %		5.4		10.4		26.7		18.0		15.9

[a]Commercial muriate of potash.
[b]Average of six determinations.
[c]Total yield of first and second cuttings.

Thus, there were in 1924, five sections of one-third acre each growing alfalfa which were, respectively, one, two, three, four, and five years old. The plats were divided in half and muriate of potash applied to the west half at the rate of 100 pounds per acre and no treatment was given the east half.

At the time the first cutting was made, all the plats where no potassium was applied, with the exception of the two-year-old alfalfa, had characteristic signs of potassium starvation on the leaves of the plants. Where potassium had been applied, there were very few plants showing potassium starvation. The method used in getting the yields from the first crops was to take six samples, a yard square, from each plat with a sampling apparatus. Each sample was weighed immediately after it was cut and part of the sample cut up and weighed for the moisture determination. Due to pressure of other work at the Experiment Station, only the plats containing the two-year-old alfalfa were harvested separately for the second cutting. The yields of alfalfa hay are given in Table 16.

In all the trials an increase was obtained from the addition of a potassium fertilizer. The small increases obtained from plats 1200 to 1300 may be due to some factor other than the supply of potassium limiting plant growth.

The amount of phosphoric acid removed by crops was estimated by calculation from the yields from the various plats. The estimates indicate that on an acre basis 179.5, 125.5, 80.2, 51, and 72.5 pounds of phosphoric acid were removed, respectively, from plats 1200, 1300, 1400, 900, and 1000 over a period of years varying from seven years with plat 1200 to three years with plat 1000 in which approximately 110 pounds phosphoric acid were added to the soil in manure and 16% acid phosphate. These estimates, when considered with unpublished data showing that increased yields are obtained from additions of phosphate fertilizers to this soil, suggest that phosphorus may have become the limiting factor for plant growth on plats 1200 and 1300 after the potassium fertilizer was added.

The results show that the increase in yield from the addition of a potassium fertilizer when no other factor was limiting growth became larger with the number of years from the time the manure was applied. This substantiates the fact, found by plant house studies, that much of the potassium in manure may be removed by the first two crops.

This fact is further substantiated by analyses made on some of the plant tissue from the first crop. The results are given in Table 17.

The difference of 41.4 pounds more removed from the plat receiving the potassium treatment accounted for practically all the potassium added in the KCl.

TABLE 17.—*Amount of K recovered from KCl by alfalfa grown on Colby silt loam, 1925.*

	Treatment None	Treatment 100 pounds muriate of potash per acre
K in air-dry alfalfa hay, %....................	0.98	1.43
Pounds K pei acre taken from plat 1000.........	59.9	101.3
Pounds difference due to KCl treatment.........		41.4

DISCUSSION OF RESULTS

Chemical analyses have shown that practically all of the potassium in manure may be available for plant growth long before the organic matter of the manure is decomposed. In fact, much of the potassium in manure is water soluble at the time it is applied to the soil. The determination by chemical means of the amount of potassium in the manure remaining available after it has been put in the soil is a rather difficult undertaking due to the fact that there are disturbing factors, such as reaction of the soil, amount of replaceable bases, moisture, and many others which nullify the results obtained. There is no chemical method which can be relied upon to give reliable information in all cases. It is obvious that the most accurate results would be obtained from a determination of the amount taken up by the growth of plants when the supply of available potassium is the only limiting factor.

The results obtained by this method show that practically all the potassium in manure is available for plant growth. In soils which were deficient in available potassium, practically all the potassium added in the manure was recovered by alfalfa, oats, and Sudan grass. In soils well supplied with available potassium, alfalfa has recovered nearly all the potassium added in the manure and oats and Sudan grass, from half to nearly all of the potassium added.

The fact that a quick-growing crop like oats recovered large amounts of the potassium added in the manure, even from soils well supplied with available potassium, is very significant in demonstrating the great availability of potassium in manure.

The results of the experiments indicate that under field conditions practically all of the potassium added in manure applications may be used up by the crops of the first two years, providing conditions are favorable for good crop growth. The utilization of the potassium from the manure is rapid when phosphate fertilizers are applied with the manure and when there is a deficiency of available potassium in the soil. In view of these facts only enough phosphorus to balance the supply of potassium in the soil should be added as a supplement to the manure. This was demonstrated very clearly by the results

obtained in the field experiments at the Marshfield Branch Experiment Station.

It is quite evident from these facts that, while the potassium in the manure is very available, the amount present in the weight of manure usually applied under field conditions is not sufficient to produce the maximum growth of crops under the conditions stated above. In view of these facts, it seems probable that very profitable results could be obtained from applications of potassium fertilizers on crops sown two or three years after the manure has been applied. The results should be particularly marked on crops like alfalfa which require large amounts of potassium for best growth.

Plants grown on soils fertilized with manure, sodium nitrate, and acid phosphate had a relatively high potassium content. Plants grown on soils fertilized with nitrogen and phosphorus fertilizers but no potassium fertilizer had a relatively low potassium content. The percentage of potassium in the plant seems to be controlled by the supply of available potassium. Therefore, the amount of dry matter produced by plant growth does not give an accurate indication of the amount of available potassium in soils.

The plants in corresponding jars were always cut, as near as possible, in the same stage of maturity. Therefore, the variations in potassium content are not due to differences in the stage of maturity.

The differences in potassium content may have considerable effect upon the quantity of carbohydrates produced in the plant. Hall (7), Stoklassa (17), and other investigators have shown that the sugar content of various crops has varied with the supply of available potassium. A difference in carbohydrate content in the plants in proportion to the difference in potassium content would cause a large variation in the nutritive value of the crops.

There is also the possibility that an excess of potassium over the amount needed by the plant for synthetic processes may be taken up and stored in the plant tissue.

EFFECT OF DECOMPOSITION OF ORGANIC MATTER IN MANURE UPON POTASSIUM MINERALS IN THE SOIL

The decomposition of rocks and minerals is brought about by the action of one or more agents. Carbonic acid derived from the decomposition of organic matter in the soil or from the carbon dioxide from the air plays a very important part in the decomposition of soil minerals. This fact would lead one to suspect that the carbon dioxide produced from the organic matter in manure should convert some of the potassium in the insoluble minerals into a soluble form which could be used by the plants.

The determination of the effect of the decomposition of the organic matter in manure upon the potassium minerals in the soil can best be made by an indirect method. A direct method fails because of the complexity of the problem. The amounts of available potassium in the soils, the amounts of potassium added in the manure, the crops grown and the number of crops in the rotation are some of the factors which must be considered.

A comparison of the amounts of total and available potassium present and the amounts of potassium removed by the crops from soils of the same type which have received regular applications of good barnyard manure over a number of years with those receiving no manure or potassium fertilizers should indicate whether the decomposition of the organic matter in the manure has affected the solubility of the potassium in the soil. That, in brief, was the purpose of this investigation.

Soils for these experiments were obtained from fields at the branch experiment stations which have received at least three applications of manure in the past 10 years.

Analyses for total potassium were made by a modified J. Lawerence Smith method. The results are given in Table 18. In calculating the pounds of potassium per acre 2,000,000, 2,500,000, and 400,000 pounds, respectively, were used for the weight of the surface 8 inches of the loams, sands, and peats.

TABLE 18.—*Difference in total K in soils due to continued fertilization with manure.*

Soil type	Treatment per rotation	Percentage total K	Pounds K per acre	Pounds K per acre less in fertilized than unfertilized soils
Peat	None	0.226	904	
Peat	12½ tons manure	0.210	840	64
Superior clay loam	None	2.473	49,460	
Superior clay loam	10 tons manure	2.297	45,950	3,510
Carrington silt loam	None	1.680	33,600	
Carrington silt loam	20 tons manure	1.595	31,900	1,700
Plainfield sand	None	0.793	19,825	
Plainfield sand	8 tons manure	0.717	17,925	1,900
Plainfield sand	400 pounds 6–8–0	0.764	19,100	725
Colby silt loam	None	1.828	36,560	
Colby silt loam A	10 tons manure	1.69	33,800	2,760
Colby silt loam B	12½ tons manure	1.786	35,720	740
Miami silt loam	None	1.955	39,100	
Miami silt loam	16 tons manure	1.987	39,640	

The results indicate that the total amount of potassium removed from the soil which had been manured was greater than the sum of

the amount removed from the unmanured soil and the amount added in the manure. This would indicate that the decomposition of the organic matter in manure may have made some of the potassium from the insoluble soil minerals available for plant growth.

While the explanation offered assumes that the total potassium content of the corresponding soils was nearly the same at the time the manure experiments were started, it is not at all improbable that such was the case. Of the six soils used in the experiment, the Miami silt loam which has been manured is the only soil to contain more total potassium than the unmanured soil The difference in this case was very close to the limit of error which is from 0.02 to 0.03% of potassium. Furthermore, in the case of the Plainfield sand where nitrogen and phosphorus were applied in a 6-8-0 commercial fertilizer, the amount of total potassium is less than the no-treatment plat and more than the manured plat. The addition of nitrogen and phosphous would make the supply of available potassium the limiting factor for plant growth and thus make conditions favorable for the depletion of the available potassium from the soil as fast as it was formed. This contention is supported by the fact that N/5 HNO_3 dissolved 0.0056% potassium from the no-treatment soil and only 0.0024% from the soil receiving 400 pounds per acre of a 6-8-0 commercial fertilizer. In the case of the soil receiving the applications of manure the condition with respect to the nitrogen, phosphorus, and potassium would not be so unbalanced However, conditions would be favorable, as shown in the first part of this paper, for the utilization of large amounts of available potassium. It would seem plausible therefore, to expect that the soil receiving the manure treatment would have less total and available potassium than the untreated soil.

AMOUNT OF N/5 HNO_3-SOLUBLE POTASSIUM IN MANURED AND UNMANURED SOILS

If the decomposition of organic matter exerted any influence upon the slightly soluble minerals in the soil, it should increase the amount of readily soluble potassium in the soil. A N/5 HNO_3 extraction was made on the manured and unmanured soils to determine if there was any difference in readily soluble potassium in the soils. The soils were obtained from plats which had grown two or more crops since the application of manure. Any differences obtained were not to be used as an index of the need of the soil for potassium fertilization, but merely to give an index to the amount of more readily soluble potassium.

PROCEDURE

Fifty grams of soil were shaken with 500 cc of $N/5\ HNO_3$ for three hours. The mixture was poured rapidly on a Buchner filter so that a layer of soil was formed in the filter. When the filtrate began coming through clear the liquid in the filter flask was poured out and refiltered. Aliquots were evaporated to dryness with a little sulfuric acid and then ignited. After cooling, a few cc of water were added and the silica and iron removed by filtration. The sulfates and any remaining iron or aluminum were removed with $Ba(OH)_2$. The Ba was then removed with CO_2. Platinic chloride was added to the filtrate and the potassium weighed as potassium platinic chloride. The results are given in Table 19.

TABLE 19.—*Differences in available K in soils due to continued fertilization with manure.*

Soil type	Manured: Percentage available K	Manured: Pounds of available K per acre	Unmanured: Percentage available K	Unmanured: Pounds of available K per acre	Increase due to manure
Peat	0.0201	80.4	0.0112	44.8	36.2
Superior clay loam	0.0084	169.0	0.0094	188.0	
Carrington silt loam	0.0080	160.8	0.0067	135.6	24.4
Plainfield sand. . .	0.0053	132.5	0.00563	140.7	
Colby silt loam A	0.00832	166.4	0.0068	136.0	30.4
Colby silt loam B .	0.00956	191.2	0.0068	136.0	55.2
Miami silt loam. .	0.01002	200.4	0.0054	108.4	92.0

The data presented in the first part of this paper indicated that practically all the potassium may be removed by the first two crops. Based on this conclusion, the larger amount of readily soluble potassium in the manured soil would indicate that the decomposition of the organic matter in the manure is converting slightly soluble potassium minerals in the soil into readily soluble forms. This contention substantiates the results found in the preceding experiment that more potassium is removed from the manured soil due to the increase in the available potassium from the difficultly soluble minerals.

The discrepancy noted in the Plainfield sands has been explained above. The differences obtained with the Superior clay loams are probably due to the difference in the total amount of potassium in the soils and a greater removal of available potassium from the manured soils. A calculation of the amount of the total potassium that is available gives 0.37% in the case of the manured soil and 0.38% in the case of the untreated soil. This would indicate that the ratio of the more soluble potassium to the less soluble potassium is the same in both soils and, therefore, based on the results with the

TABLE 20.—*Variations in the potassium content of plants.*

Soil type	Crop Analyzed: Oats		Sudan Grass		Alfalfa		Mgms of available K in manure
	Unmanured	Manured[a]	Unmanured	Manured[a]	Unmanured	Manured[a]	
Quartz sand, 1924	4.14[b]	4.18	1.45	2.48[c]	1.88	3.04	—
Quartz sand, 1924	4.09	4.32	1.50	2.67	1.39	2.72	—
Quartz sand, 1925	—	—	—	—	1.10	1.43	—
Quartz sand, 1925	—	—	—	—	0.82	1.59	—
Silty clay loam	1.56	2.30	—	—	1.03	1.96	919
Silty clay loam	1.57	2.23	—	—	—	1.91	919
Plainfield sand	0.74	1.52	0.73	1.38	0.84	1.16	270
Plainfield sand	0.77	1.66	0.67	1.39	0.91	1.38	270
Miami silty clay loam	2.30	2.72	1.28	1.70	1.14	1.51	270
Miami silty clay loam	2.28	—	1.31	1.65	1.31	1.51	270
Miami silty clay loam	—	—	—	—	1.22	1.37	172
Miami silty clay loam	—	—	—	—	1.19	1.35	172
Miami silt loam	1.01	1.45	0.80	0.98	0.91	1.30	270
Miami silt loam	1.00	1.30	0.79	0.95	0.93	1.33	270
Colby silt loam	—	—	—	—	0.98	1.41[d]	40 pounds

[a]For crops in quartz sand the left hand columns are the analyses from crops grown with 8 tons manure and the right hand columns with 16 tons manure containing 613 and 1,326 mgms, respectively, in 1924, and 180 and 360 mgms, respectively, in 1925.

[b]Each figure is the average of duplicate analyses on plant tissue from the same jar.

[c]Sudan grass sown without any additional fertilizer after the oat crop had been harvested.

[d]KCl added 100 pounds per acre.

other soils, a larger amount of readily soluble potassium has been removed by the plant growth from the manured soils.

VARIATIONS IN POTASSIUM CONTENT OF PLANTS

It is generally recognized that different species of plants require different amounts of plant food in order to make good growth. If this is true, the amount of growth produced by a crop should indicate the amount of any one plant food element which is available to that crop when that element is the limiting factor. That this is not true, at least with the supply of available potassium, is shown by analyses (Table 20) made by the writer on crops grown on different soils having varying amounts of available potassium when that element was the limiting factor.

The data show that whenever available potassium was added to the soil there was a marked increase in the amount of potassium in the plant tissue. A comparison of the increase in yields with the increase in the potash content of the plant indicates that there is absolutely no correlation between the two. Neubauer and Schneider (12) have reported similar results.

The results of this experiment give additional significance to the results of the two previous experiments, but will have greater significance in the explanation of the potassium balances to be presented for fields for which reliable records are available.

ESTIMATION OF THE POTASSIUM BALANCE FOR VARIOUS SOILS

It was not possible to make an exact determination of the total amount of potassium removed from the soils by crops because no analyses for potassium had been made on the plant tissue. However, a fairly accurate account of the situation can be made by using average figures, as compiled by Henry (11), for the potassium content of the various crops grown. These results, when interpreted with

TABLE 21.—*Average K content of some crops.*

Crops	Percentage K in grain	Percentage K in hay or straw and chaff
Corn	0.474	0.907
Corn fodder	——	0.740
Corn cob meal	0.391	——
Oats	0.409	1.472
Wheat	0.742	0.524
Barley	0.399	0.882
Rye	0.483	0.716
Soybeans	1.048	0.865
Soybean hay	——	1.140
Timothy	——	1.181
Red clover	——	1.546
Alfalfa	——	1.489

consideration of the results of all the preceding experiments, should give reliable information as to what has taken place.

The yields used, unless otherwise stated, were taken from the official records for the experimental plats described. The analyses used for estimation of the amount of potassium removed by the crops are given in Table 21.

POTASSIUM REMOVED BY CROPS FROM PLAINFIELD SAND AT HANCOCK EXPERIMENT STATION

The nature of the fertilizer treatments on the plats at Hancock, in connection with the fact that the soil is very deficient in available potassium, offers an unusual opportunity to study the effect of the decomposition of the manure upon the difficultly soluble potassium minerals in the soil. A comparison of the no-treatment plat A3 with plat A8 receiving 400 pounds of a 6-8-0 fertilizer should indicate the maximum amount of potassium the plants can obtain from the soil without the aid of some factor not in any way connected with the plant. A comparison of plats A1 and A2, receiving 8 tons of manure plowed under and topped dressed, respectively, should give some idea as to the effect of the fertilizing elements in the manure and also the effect of the decomposition of the organic matter upon the potassium compounds in the soil. The manured plats should give, respectively, the effect on the soil of the decomposition the first year of large amounts of manure as compared with the decomposition of moderate amounts the first year and of small amounts the second year when the partially decomposed manure remaining would be plowed under. A comparison of the results obtained from the calculations, combined with the results of the determination for total and N/5 HNO_3-soluble

TABLE 22.—*Estimated amounts of potassium removed by crops from Plainfield sand at Hancock.*

Crops	Pounds K removed per acre: Plat A1, 8 tons manure plowed under	Plat A3, check	Plat A8, 400 pounds 6-8-0	Plat A2, 8 tons manure top dressed
Rye grain	6.9	3.8	4.8	6.2
Rye straw	15.8	8.9	10.6	14.6
Soybean grain	5.6	4.4	4.8	5.3
Soybean dry matter	15.2	11.9	11.5	12.7
Corn grain	15.5	1.0	3.8	10.9
Corn stover	67.2	10.9	12.9	43.7
Soybean hay	22.3	24.1	27.9	33.0
Total	148.5	65.0	76.3	126.4
Amount over check	83.6	——	11.4	61.5

potassium, should give very reliable information as to what has actually occurred in the soil.

Calculations were made from the yields of the crops grown from 1920 to 1924, inclusive, on plats A1, A2, A3, and A8 from field L1. The plats received fertilizer treatments in 1920 and 1922. The crops from which the data were calculated were two of rye and one each of corn, soybean hay, and soybeans for grain. The results calculated as pounds of potassium removed per acre are given in Table 22. The variations in the yields are in the same ratio as the differences in the amounts of potassium removed from the soil.

Analyses of manure samples for the past three years indicate that the maximum amount of potassium contained per ton would not exceed 5 pounds. While the amount of potassium applied in the 16 tons of manure probably did not exceed 65 pounds, the maximum amount of 80 pounds will be used in the discussion of the results obtained.

A comparison of the results obtained for plats A3 and A8 indicates a removal of 11.4 pounds more potassium from the soil when large applications of available nitrogen and phosphorus were made. The larger growth made by the crops on plat A8 indicates that there was, in all probability, a much larger root system than in the no-treatment plat. If this were true, the plants would have a greater power to feed upon the potassium in the soil, and, due to the unbalanced condition brought about by the addition of nitrogen and phosphorus, should use most of the readily soluble potassium in the soil. That this actually took place is shown by the fact that the amount of potassium in the soil soluble in N/5 HNO_3 is only 0.00247% from plat A8 as compared with 0.00563% in the soil from the no-treatment plat. This is further substantiated by the fact that there are 725 pounds less of total potassium in the soil from plat A8 than from the no-treatment plat.

The results from plat A2, which received a top dressing of 8 tons of manure, show that about twice as much potassium was removed as from the no-treatment plat and about 60% more than from the plat receiving 400 pounds of a 6–8–0 commercial mixture. However, the results of previous experiments on the amount of potassium recovered by plants from manure would indicate that the amount would be much greater. If a difference of 20%, which is a conservative estimate as shown by the data in Table 22, is assumed as the average difference in the potassium content of the plants, the amount of potassium removed from plat A2 would be 152 pounds. Providing that this was all that was available, it would just account for all the

potassium added in the manure plus the amount available from the soil to a plant feeding almost to its maximum capacity upon the more soluble potassium compounds in the soil. However, analysis shows that there are 71 pounds per acre more of N/5 HNO_3-soluble potassium in the manured soil than in the soil receiving 400 pounds of a 6-8-0 commercial mixture. That amount of potassium, therefore, must have been released from the slightly soluble potassium minerals by some factor due to the addition of the manure.

It is universally accepted by scientists that solution, oxidation, and carbonation are three of the most important chemical weathering agencies which convert slightly soluble minerals into more readily soluble forms. If this is true, part of the increase of more readily soluble potassium in the manured soil may be due to the carbon dioxide which was produced from the decomposition of the organic matter in the manure.

Analyses to determine the differences in amounts of total potassium in the soils show that there are 1,175 pounds total potassium less in the manured soil than in the soil receiving 400 pounds of 6-8-0 commercial fertilizer. This would indicate that the decomposition of the organic matter in the manure has had an appreciable action in converting difficultly soluble potassium into soluble forms which have been carried to the plant in the soil solution and subsequently removed by the plants.

The fact that plants feed not only upon the plant food elements which are made soluble in the immediate vicinity of the root hairs, but also upon plant food elements carried to them by the soil solution is demonstrated by the large amount of data of fertilizer experiments where the soils have been top dressed with fertilizers. It seems, therefore, that a considerable amount of potassium has been made available by the decomposition of the organic matter in the manure, and subsequently removed by the plant from the soil solution.

The data from plat A1 show even more strikingly the effect of the decomposition of the organic matter in the manure. In this case the manure was plowed under and therefore the decomposition of large amounts of organic matter would begin immediately. If it is assumed that the same average difference of 20% exists in the potassium content of the crops and the same procedure is used for computing the potassium balance as was used for the preceding plats, a balance of 22 pounds more of potassium was removed from the soil than was removed from the soil of any other plat. This difference would be even larger if the soybeans had not lodged on A1 in 1924 with the result that the yield of hay was smaller than from any other plat.

The conclusions given above are based upon investigations with a number of soils but due to lack of space only the data for the Plainfield sand can be presented.

The decomposition of manure is not the only factor which may affect the availability of the potassium from the difficultly soluble soil minerals. Increased root development with a subsequent increase in feeding power of the plants may cause more potassium to be removed from the soil. Also, the larger root development will leave a larger organic residue in the soil which, on decomposition, will liberate available potassium for plant growth.

These factors have been given due consideration in the foregoing discussion. The results obtained indicate that the decomposition of the organic matter in the manure may play an important part in converting difficultly soluble potassium minerals into soluble forms which can be used by plants.

SUMMARY

Chemical analyses were made to determine the variations in the amount and availability of potassium in manure.

Alfalfa, oats, and Sudan grass were grown in quartz and soil cultures which had received various fertilizer treatments. In this manner some indication of the availability of the potassium in the manure was obtained.

Analyses for potassium were made on the plants from jars which had received fertilizer treatments favorable for the utilization of the largest amounts of potassium from the soil and from the soil plus manure. The amount of potassium recovered from the manure was calculated.

A study was made by an indirect method to determine the effect of the decomposition of the organic matter in the manure in converting insoluble potassium minerals in the soil into forms that can be used by plants. The factors used to develop the conclusions were the differences in total and available potassium in plats which had received no treatment and manure applications, respectively, over a period of years; the variations found in the potassium content of plants which had received, respectively, no potassium and potassium in the fertilizers applied; and the total amount of potassium removed by crops from manured and no-treatment plats over a period of five or more years.

A summary of the results obtained in these experiments follows:

1. The amount of potassium per ton of manure may vary from 3 to 20 pounds. That produced by the same herd may vary at different times from 5 to 12 pounds per ton.

2. All the potassium in the manure is available for plant growth before much of the organic matter in the manure is decomposed.

3. Alfalfa, oats, and Sudan grass recovered practically all of the potassium applied in manure to quartz cultures and soils deficient in available potassium.

4. From soils well supplied with available potassium, alfalfa recovered practically all the potassium applied in manure, while oats and Sudan grass recovered from half to nearly all that applied in the manure.

5. Top dressings of 100 pounds of muriate of potash on alfalfa growing in Colby silt loam gave very marked increases. Ten tons of manure and 600 pounds of 16% acid phosphate had been applied from three to five years previous to the top dressing with muriate of potash.

6. The percentage of potassium in the plant was determined by the amount available for plant growth when the supply of potassium was the factor limiting plant growth. The percentage was always higher in plants grown on soils to which potassium was applied in manure.

7. The amount of dry matter produced by plant growth did not give an accurate indication of the amount of available potassium in the soil.

8. Most soils fertilized with manure had more N 5 HNO_3-soluble potassium and less total potassium than adjoining soils which had never received any fertilizer treatment.

9. Crops removed considerably more potassium in addition to that added in the manure, over a period of years, from plats fertilized with manure than they did from unfertilized plats.

10. The decomposition of the organic matter in manure may convert some of the insoluble potassium minerals in the soil into forms which can be used by the plant.

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NOTES

DETERMINING SOIL MOISTURE RAPIDLY AND ACCURATELY BY METHYL ALCOHOL

In a former communication[1] the use of alcohol was proposed as a basis for a very rapid means of determining the moisture content of soils and possibly of other materials. The form of alcohol that was then suggested was ethyl alcohol. In order to ascertain whether there are other liquids that would be more satisfactory than ethyl alcohol, an investigation has been conducted in which a large number of liquids have been examined.

It has been discovered that of all the liquids studied, methyl alcohol seems to be the most satisfactory, as it is the most powerful dehydrating agent. Indeed, this form of alcohol seems to be able to replace or reduce the moisture content of soils down to practically the absolutely dry basis, as will be readily seen from the data below. These data were obtained by placing about 20 grams of air-dry soil in a 100 cc cylinder, drying it in an oven at 110° C for 24 hours, cooling it in a desicator, and then trying to recover the water added by 50 cc of alcohol. This would seem to be a more accurate and reliable procedure than taking duplicate samples from moist soil for comparison, since it is so difficult to take absolutely duplicate samples.

	Percentage of water recovered from water added to oven-dry soils
Sand	100.05
Loam	100.03
Clay	99.99
Muck	99.01
Silica gel	99.30

These results indicate that by the use of methyl alcohol the moisture content of soils can be determined as absolutely as by the oven method. These results may appear incredible, but they have been checked in various ways. It is possible in some cases, as in mucks, that any traces of water that the alcohol fails to extract or replace, are compensated by traces of material that the alcohol may dissolve out.

By this method the hygroscopic moisture content of soils can also be determined.

Although not extensively studied, it seems probable that the methyl alcohol can also be used to determine the moisture content of flours and possibly of other organic materials. Here, however, an error may arise due to some substance dissolved out by the alcohol.

[1]This Journal, Vol. 19: 469-471. 1927.

The big feature and advantage of the alcohol method for moisture determination is its great rapidity. With the exception of some clay soils in which the fltration is slow, the moisture content can be determined in about seven minutes, and in much less time in some soils.

Another important feature of the method is that it can be used under field conditions. The necessary apparatus, including a small hypothecary balance, can be carried to the field to make moisture determinations. This field outfit, together with directions, will be described in a later publication.

The directions for executing a moisture determination by methyl alcohol are the same as those already published for ethyl alcohol. There are five points in the procedure, however, to which one must always pay special attention First, the soil must be stirred with a strong rod and reduced to the particle state so that the alcohol can come into intimate contact with the entire soil mass. Second, the liquid must always be filtered Third, great care must be taken to prevent evaporation. This can be accomplished chiefly by keeping the funnel covered during fltering Fourth, the temperature of the liquids should always be recorded and reduced to the same basis. Fifth, in calibrating the hydrometer the specific gravity of the absolute alcohol should be taken under controlled temperatures. Allowing the alcohol to stand in running tap water to attain the temperature of the latter is sufficient.

It is advisable to use absolute methyl alcohol, as in this form it is a more powerful dehydrating agent.

In case of soils containing more than 50% moisture, such as mucks and peats, only about 10 grams of soil should be used to 50 cc of alcohol.—GEORGE J. BOUYOUCOS, *Research Professor in Soils, Michigan State College, East Lansing, Mich.*

COMPETITION BETWEEN ADJACENT ROWS OF CORN

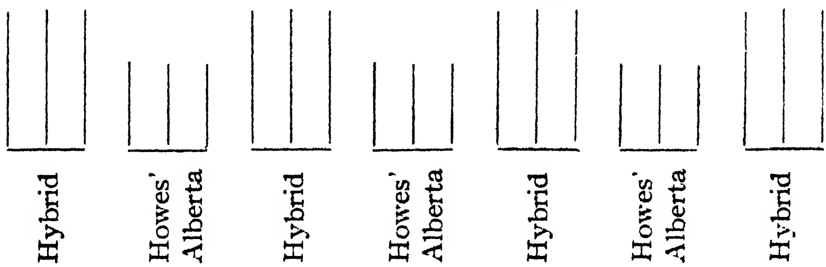
This brief note is prompted by the interesting results presented by G. H. Stringfield[1] on intervarietal competition among small grains which show that under the conditions of his experiment there was no significant competition between adjacent border or guard rows of different oat and wheat varieties.

In the course of a field plat test conducted the past season at the North Dakota Experiment Station at Fargo two types of corn having decidedly different habits of growth were grown side by side. The two

[1]This JOURNAL, Vol. 19: 971–983. 1927.

types in question were represented by the variety Howes' Alberta flint and by a hybrid between this variety and an acclimated strain of Minnesota No. 13. Howes' Alberta flint is an extremely early variety and grew to an average height of about 4 feet under the conditions of this test, while the hybrid attained a height of about 6½ feet. Difference in vigor was further attested by the comparative yields which were 20.1 bushels per acre for Howes' Alberta and 40.0 bushels per acre for the hybrid.

The corn was grown in groups of three rows in order that the middle row might be harvested for comparative yield. There were three replicates of Howes' Alberta and five of the hybrid. The rows extended in a north and south direction. Their relative position in the field is indicated in the following diagram.



In the case of Howes' Alberta each of the three rows in each replicate was harvested separately. The yields calculated to bushels per acre were as follows:

First replication		Second replication		Third replication	
Border	19.4	Border	21.6	Border	19.7
Middle	18.8	Middle	22.0	Middle	19.6
Border	17.7	Border	21.2	Border	23.0

Average borders 20.4

Average middles 20.1

It is evident that in this instance Howes' Alberta was not affected by competition with the adjacent hybrid rows.—P. J. Olson, *Assistant Agronomist, North Dakota Experiment Station, Fargo, N. Dakota.*

BOOK REVIEWS

BEAN CULTURE

By E. V. Hardenburg. New York: The Macmillan Co., 254 pp. 40 fig. 1927. $3.00.

This is a most attractive, well-written, and useful addition to the Rural Science Series, edited by Professor L. H. Bailey. It is the most comprehensive discussion of beans in their commercial aspect known to the reviewer and appears equally strong in the many aspects presented, though necessarily limited in the descriptions of varieties. Outstanding characteristics, regions where most grown, and special adaptabilities, strong points and weaknesses are, however, concisely and accurately given for about 25 leading field beans, and nearly as many Lima beans; but the garden, truck-crop and cannery varieties are less definitely handled.

It might have served a useful purpose had the author included a short chapter on beans in the home garden, with a list of several varieties, now entirely omitted, whose chief recommendation is quality. While this character of beans is not unimportant in truck-crop beans, it is frequently subordinated to productiveness and an attractive exterior. However, to have included all varieties for gardens, popular in some section of the country, would probably have exceeded the size of book desired, for their number is legion. Mention might well have been made of several promising newer varieties.

The book opens with a few pages bringing out the importance of beans as a world crop, including brief notes on bean history, devotes a short chapter to classification following Bailey for species grouping of beans extensively grown in America, using a modification of Corbett's grouping of *P. vulgaris*, and the Jarvis-Gilmore limits for market classes of shell or baking beans. Piper and Jarvis' five oriental species of beans known in America are also mentioned. Following the chapter devoted to types and varieties of bush and pole beans are interesting discussions, usually with up-to-date data and experimental evidence, on economics of production, climatic and soil relationships, culture (in three chapters covering rotation, fertilizing and seedbed preparation, seed, and planting and cultivation), separate chapters on diseases and on insects, on handling the matured crop, on marketing, on quality of beans, on breeding and improvement, on string beans as a truck crop, on the bean-canning industry, and on dry-land cultivation of beans. Additional chapters discuss Lima beans, cowpeas and soybeans, and miscellaneous kinds of beans.

Among the latter are included the broad bean (technically not a bean, but more closely allied to the peas, as also are the chick-pea, lentils and lupines, which are also discussed), the velvet bean, jack bean, sword bean, kudzu, hyacinth bean, and carob.

Little but praise can justly be given to the work as a whole, either as to matter or manner of presentation, general form, typography, or editing. Of typographical errors, but one was noticed in a careful, but rapid reading, the misspelling of bumble bees on page 20; and

the continuation of the running head for diseases over a page or two of insects.

In the author's distinction of beans from peas by seed characters, perhaps "flat" might better be changed to some other term; as few beans, except the Sieva and large limas not of the "potato" type and some pole beans, strike one as flat.

The reviewer failed to find any reference to "hard-shell" of beans, a condition seriously affecting both the cooking and baking quality of beans improperly stored, and the germination unless the improper storage condition is changed for a time before planting. Attention might have been called, also, to the three or more types of bacterial blight, to some of which varieties are quite differently susceptible.

Apparently no mention is made, under harvesting, of the new, small, field-stack method of handling, by which damage from wet weather is reduced to a minimum.

The author also discusses *Epilachna corrupta* both as Mexican bean beetle and as bean lady-bird; but fails to mention the bean-leaf beetle (*Ceratinia trifurcata*) which is occasionally a noteworthy bean pest in parts of the East and often in Kansas and some adjoining territory.

However, these very minor errors or omissions detract only to the slightest extent from a work creditable alike to author, editor, and publishers; and one which should find wide use both by teachers and students, and by bean-growers not only as a reference book but also as a most readable discussion of one of America's leading vegetables. (F. H. H.)

HANDBUCH DES GETREIDEBAUES (HANDBOOK OF CEREAL CULTURE)

By J. Becker-Dillingen, Berlin: Paul Parcy, 627 pp., 94 fig. 1927. $6.00 in United States.

A chapter of 102 pages of general discussion of grain crops is followed by detailed chapters on rye, wheat, barley, oats, and corn, with shorter chapters on rice, millet, the sorghums, and buckwheat and a few pages each devoted to crab grass, floating fescue, canary grass, *Chenopodium quinea*, and *Tropa natans*.

The chapters on rye, barley, wheat, and oats constitute over half of the book and are the most useful. With characteristic Teutonic thoroughness and with an amazing wealth of detail, the author discusses the history, distribution, botanical characteristics, cultural methods, soil relations, fertilizer requirements, chemical composition, diseases, and breeding practices The chapters on each crop begin with the scientific name and a list of common names in various languages, 94 common names being listed for rye alone.

A mass of experimental data is included and a wide field of literature, mainly European, is cited.

The chapter on maize is somewhat disappointing, partly, perhaps, because the reviewer is more critical of this material, but more probably, because the author was forced to draw largely on American literature for his facts and was unable to distinguish between the more important and the less important contributions and apparently failed

to consult much of the valuable literature published in our station bulletins. Nevertheless, the summary of genetic studies in corn is as complete as can be found in any book on corn published in this country, although there are, unfortunately, numerous omissions and errors. The present program of corn improvement by selection in self-fertilzed lines is briefly discussed, but the important contributions of Shull, East, Hayes, and Jones toward the development of this method are not mentioned.

The book is not difficult to read, or to be precise, is less difficult to read than are the large majority of German publications. Written in the English language it might be useful as a text. In its present form it deserves a place as a reference book for instructors and investigators in grain crops, and will prove valuable in presenting the European viewpoint and in making easily available the more important facts from European research with small grains. (P.C. M.)

GREEN MANURING

By Adrian J. Pieters. New York: John Wiley and Sons, Inc., XIV+356 pp., 80 fig. 1927. $4.50.

"Green manuring" is a comprehensive, thorough, up-to-the-minute discussion of green manuring. Approaching the subject from the standpoint of food supply, population, and the maintenance of soil fertility, the author briefly reviews the history of green manuring before entering upon a more technical discussion of organic matter, its decomposition, its benefits, nitrogen fixation, and the chemical composition of green manuring plants. Following this are matters of a more practical nature, occupying approximately one-half of the book, and including such topics as rates of seeding, crops used, quantity of green matter produced per acre, yields of other crops following green manuring, and special problems in various sections of the United States as well as in other countries.

Though such subjects as soil organisms, inoculation, and enumeration of crops contain material to be found in other sources, yet each topic is treated with particular reference to green manuring, amply justifying its presence from this standpoint alone. The advantage of having drawn together in one volume the latest information from all sources upon the subject of green manuring is evident. The bibliography contains 352 references. The illustrations are well chosen. The index is complete. "Green Manuring" is especially welcome at a time when humus and organic matter are of increasing interest. (H. B. T.)

AGRONOMIC AFFAIRS

A NEW EDITOR FOR THE JOURNAL

Beginning with this number of the JOURNAL a new editorial arrangement becomes effective. Dr. R. W. Thatcher, for the past six years Editor of the JOURNAL, was forced to relinquish the editorship because of pressure of other duties as President of Massachusetts Agricultural College. Consequently, J. D. Luckett, Assistant Editor and Business Manager, was elected Editor by the Executive Committee at the last annual meeting of the Society, with an Advisory Editorial Committee comprised of Dr. R. W. Thatcher, *Chairman*, Dr. T. L. Lyon, and Dr. C. R. Ball. It is confidently expected that the same high standards that have characterized the JOURNAL in the past will prevail under this new arrangement.

"SUPERPHOSPHATE (ACID PHOSPHATE)"

Following recommendations by the Committee on Definition of Terms of the Association of Official Agricultural Chemists and the Board of Directors of the National Fertilizer Association, and in view of the expressed purpose of many farm paper editors to adhere to these recommendations, the Advisory Editorial Committee of the American Society of Agronomy suggests that the expression "Superphosphate (acid phosphate)" be used in the JOURNAL wherever acid phosphate is referred to, the words in parenthesis to be dropped one year hence. This suggestion goes into effect with this number of the JOURNAL.

A NEW SERVICE TO MEMBERS OF THE SOCIETY

Two sections, one to be known as "Positions Wanted" and one as "Positions Available," will be included in the advertising pages of the JOURNAL whenever the demand arises in order that members of the Society seeking positions may be put in touch with vacancies in agronomy occurring in the several institutions served by the JOURNAL. A fee of one dollar for each insertion of notices not exceeding 50 words in length will be charged for this service. Notices should be sent to the Editor who will see that they appear as soon as possible. Provision will be made for identification by a key number.

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AMMONIFICATION IN YAHOLA SOILS[1]

HENRY F. MURPHY[2]

Ammonification studies have been carried out by many investigators. Such studies may or may not have a great deal of value, yet no doubt they are of certain value in that they show the rate of decomposition of some of the cruder nitrogenous materials. The ammonia produced from this bacterial action is a simpler form of nitrogen and one that comes nearer being usable by plants than the original material, therefore ammonification studies are not without interest. No attempt will be made to review the extensive literature on this subject, although a short review can be had by consulting a previous paper[3] by the writer.

PLAN OF EXPERIMENT

One of the outstanding bottom land soils found in the Red Prairies is known as Yahola. This soil is quite productive as a rule where the water table is not too close to the surface or where it is not subject to too much overflow. It has more or less loose subsoil as a rule, the looseness increasing with depth. The surface soil is heavier than the subsurface, and the subsurface heavier than the subsoil. Overflow conditions no doubt have brought this about. The surface soil is chocolate red as a rule and, as depth increases, the color grows lighter until there is found as a subsoil a light salmon-colored sandy material with increased coarseness. This soil was formed and is being formed from the eroded material from the red lands (Vernon series) of the Red Prairies.

[1]Contribution from the Department of Agronomy, Oklahoma A. & M. College, Stillwater, Okla. The writer wishes to make acknowledgment to Dr. Wallace Macfarlane, who started this work, and to D. R. Johnson, who carried it on until 1920. Received for publication October 27, 1927.

[2]Associate Professor of Agronomy.

[3]Ammonification in red prairie soils. Jour. Amer. Soc. Agron., 18:177–183. 1926.

For this experiment Yahola very fine sandy loam was selected as typical of the series. Ten one-twentieth acre plats (124.45 x

TABLE 1.—*Fertilizer plan.*

Plat No.	Treatment
1	Check
2	5 tons ground limestone
3	2.8 tons calcium oxide
4	5 tons ground limestone+8 tons manure
5	2.8 tons calcium oxide+8 tons manure
6	Check
7	3 tons ground limestone
8	1.68 tons calcium oxide
9	3 tons ground limestone+8 tons manure
10	1.68 tons calcium oxide+8 tons manure

TABLE 2.—*Showing milligrams of ammonia per 100 grams of Yahola soil.*

Plat No.	1918	1920	1921	1922	1923	Average
			JUNE			
1	98	69	174	89	—	92
2	105	52	170	94	—	105
3	145	87	133	141	—	126
4	69	88	169	149	—	119
5	131	103	164	165	—	141
6	95	118	130	113	—	114
7	71	91	154	122	—	110
8	74	100	126	143	—	111
9	60	77	112	156	—	101
10	74	68	131	99	—	93
			JULY			
1	—	47	254	231	141	168
2	—	49	198	243	121	153
3	—	66	191	193	104	138
4	—	59	190	248	164	165
5	—	89	188	261	251	197
6	—	46	152	238	100	134
7	—	76	215	213	106	152
8	—	65	196	317	94	168
9	—	59	224	218	89	147
10	—	44	216	215	97	143
			AUGUST			
1	76	107	149	139	147	144
2	109	107	185	133	257	158
3	90	132	185	144	263	163
4	121	126	160	150	253	162
5	96	139	205	148	260	169
6	73	132	176	74	227	137
7	108	141	170	124	221	153
8	118	106	169	161	285	168
9	110	112	175	156	308	172
10	119	143	132	156	229	156

17½ feet) were laid out. No border was used in separating the plats. The materials as given in Table 1 were applied to the respective plats in the spring of 1917 and again in the spring of 1921.

RESULTS

Except where otherwise stated, samples of soil were collected from each of the plats during the three summer months of June, July, and August. These samples were taken from areas approximately 10 x 20 x 6 inches deep by means of a sterile spatula. Each sample was thoroughly mixed, placed in a sterilized soil can, and taken to the laboratory where a moisture determination was made of a representative sample.

For the ammonification test duplicate samples of 100 grams (dry basis) of soil were weighed out and placed in sterlized glass tumblers. To each tumbler was added 5 grams of dried blood. The sample was then thoroughly mixed and raised to optimum moisture conditions for the respective soil. An additional 12 cc of water were added to take care of the dried blood. The samples were then incubated at room temperature for seven days and the ammonia content determined by the aeration method as recommended by Potter and Snyder.[4] The results are given in Table 2.

TABLE 3.—*Showing a general average ammonification per season for the different treatments on Yahola soil in milligrams per 100 grams of soil.*

Soil treatment	June 1918, 1920–22 inclusive, 4-year average	July 1920–23 4-year average	August 1918, 1920–23 5-year average	Average per season
5 tons $CaCO_3$ or equivalent CaO	116	146	161	141
5 tons $CaCO_3$ or equivalent CaO+manure	130	181	166	159
Average of heavy lime treatments	123	163	163	150
3 tons $CaCO_3$ or equivalent CaO	110	160	160	143
3 tons $CaCO_3$ or equivalent CaO+manure	97	145	164	135
Average of light lime treatments	104	153	162	140
Average of all $CaCO_3$ treatments (no manure)	107	153	156	139
Average of all CaO treatments (no manure)	119	153	165	146
Average of all check treatments	103	151	140	131
Average of all $CaCO_3$ treatments with manure	110	156	167	144
Average of all CaO treatments with manure	117	170	163	150
Average of all limestone treatments	109	154	161	141
Average of all CaO treatments	118	162	164	148
Average of all manure treatments	113	163	165	147

[4]Potter, R. S., and Snyder, R. S. The determination of ammonia in soils. Jour. Ind. and Eng. Chem., 7:221–226. 1915.

DISCUSSION

It would seem from a review of Table 3 only that the various soil treatments had increased ammonification, but when Table 2 is considered it will be observed that the variations are so great for the same treatment on different years and even for different periods of the same year that the average results have very little value.

For the June to August period of 1921 rather high ammonification for all treatments and checks occurs, while if the same period is taken for the year 1920 the results are much lower. In fact, during any one of these months in 1920 the ammonification was lower than for any corresponding month of 1921 and did not generally reach as high a point during the whole season as it was in June of 1921. In 1922 the highest peak generally for the three months was for July, while for 1923 August produced much higher ammonification than did July. Again considering 1920, July gave the lowest ammonification of the three months.

Omitting the year 1918 where no data are available for July, it can be observed that ammonification was not as high in June as it was for one or the other months of July or August for any of the other years.

For no monthly period did any one soil treatment show to advantage over some other treatment.

All of these comparisons go to show that ammonification, while no doubt of importance, is quite a variable biological activity.

SIZE OF PLAT AND NUMBER OF REPLICATIONS IN FIELD EXPERIMENTS WITH SOYBEANS[1]

T. E. Odland and R. J. Garber[2]

INTRODUCTION

In varietal experiments with different farm crops the question of what size of plat and how many replications to use in order to obtain reliable results is of prime importance. For the sake of economy in land and labor it is desirable to have the plats as small as possible and replicated a minimum number of times. On the other hand, it is of even greater importance that the plats be large enough and sufficiently often replicated to make the results reliable. Although considerable work has been done in determining the size of plat required for tests with small grains, potatoes, and a number of other crops, a search of the literature does not reveal any experiments of this nature with soybeans.

The object of the study reported in this paper was to find the minimum size of plat and number of replications of this size of plat necessary for varietal tests with soybeans under the conditions prevailing where these experiments were made. At the West Virginia Experiment Station the soybean varietal trials are carried on in rod rows which are 30 inches apart. Each plat is replicated three times making four plats of each variety. The particular size of plat and number of replications chosen were made for convenience and on the basis of experience with other crops.

Inquiries addressed to a number of experiment stations revealed the fact that various lengths of row and number of replications are used by the different stations.

In West Virginia the Wilson soybean has been the most popular and is by far the most widely grown variety. This variety is also used for the check plats in the varietal experiments. For these reasons it was used in the experiments reported in this study.

PLAN OF EXPERIMENT

The tests reported herein extended over a period of two years, *viz.*, 1925 and 1926. In 1925 the crop was harvested for forage and in 1926 for seed. The soybeans were planted in rows 30 inches apart and running the full length of the area on which the test was located.

[1]Contribution from Department of Agronomy, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Approved for publication as Paper No. 39 by the Dean and Director. Received for publication October 28, 1927.

[2]Associate Agronomist and Head of Department, respectively.

TABLE 1.—*Yield of soybean hay in tons of air-dry material per acre for each 8-foot section of row in 1925.* (Yields recorded to nearest 0.1 ton.)

Series of 8-foot rows	Row Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1.7	1.6	1.9	2.1	1.8	2.0	1.9	2.0	2.0	1.8	1.8	1.9	1.6	1.8	1.8	1.8	2.0	2.0	1.9	2.0	2.0
2	1.8	1.6	1.8	1.7	1.6	1.5	1.8	1.9	1.8	2.1	1.9	1.7	1.7	1.9	1.8	1.7	1.8	1.7	1.7	1.9	1.8
3	1.3	1.4	1.6	1.3	1.6	1.5	1.5	1.6	1.7	1.7	1.6	1.5	1.2	1.6	1.4	1.8	1.7	1.5	1.4	1.7	1.6
4	1.6	1.4	1.6	1.8	1.3	1.6	1.8	1.4	1.6	1.5	1.6	1.2	1.5	1.5	1.8	1.8	1.9	1.9	1.5	1.7	1.8
5	1.6	1.8	1.6	1.9	1.8	1.5	1.6	1.5	1.6	1.3	1.5	1.3	1.3	1.7	1.9	1.5	1.7	1.4	1.5	1.6	1.8
6	1.6	1.6	1.7	1.8	1.5	1.4	1.5	1.3	1.3	1.3	1.4	1.3	1.0	1.6	1.8	1.6	1.8	1.5	1.7	1.6	1.6
7	1.4	1.4	1.8	1.8	1.6	1.4	1.6	1.4	1.6	1.3	1.5	1.4	1.3	1.5	1.2	1.7	1.6	1.5	1.6	1.7	1.6
8	1.3	1.5	1.7	1.7	1.7	1.5	1.6	1.7	1.4	1.4	1.4	1.5	1.2	1.5	1.4	1.3	1.6	1.4	1.4	1.9	1.8
9	1.4	1.4	1.4	1.5	1.4	1.9	1.6	1.2	1.6	1.4	1.5	1.5	1.1	1.4	1.4	1.7	1.5	1.7	1.6	1.7	1.5
10	1.4	1.7	1.5	1.7	1.6	1.7	1.6	1.6	1.5	1.8	1.7	1.5	1.1	1.6	1.6	1.4	1.5	1.4	1.6	1.7	1.2
11	1.2	1.5	1.5	1.7	1.6	1.3	1.4	1.3	1.6	1.5	1.4	1.7	1.3	1.7	1.5	1.8	1.8	1.5	1.4	2.0	1.9
12	1.5	1.4	1.4	1.5	1.2	1.3	1.7	1.7	1.6	1.6	1.4	1.6	1.3	1.8	1.4	1.6	1.5	1.8	1.8	2.0	1.7
13	1.7	1.5	1.8	1.7	1.6	1.6	1.5	1.7	1.6	1.6	1.6	1.8	1.6	1.6	1.6	2.0	1.9	2.2	1.7	1.9	1.6
14	1.4	1.6	1.3	1.5	1.6	1.5	1.5	2.1	1.6	1.9	1.6	1.9	1.4	1.7	1.6	1.7	1.7	1.7	1.7	2.1	1.6
15	1.3	1.4	1.4	1.3	1.4	1.3	1.3	1.6	1.4	1.3	1.2	1.3	1.3	1.6	1.4	1.3	1.5	1.6	1.5	1.6	1.3
16	1.5	1.5	1.3	1.3	1.3	1.5	1.4	1.6	1.5	1.4	1.2	1.5	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.8	1.3
17	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.4	1.5	1.5	1.3	1.6	1.3	1.4	1.4	1.5	1.6	1.6	1.4	1.9	1.2
18	1.3	1.2	1.2	1.5	1.2	1.4	1.1	1.5	1.2	1.5	1.2	1.4	1.4	1.5	1.6	1.6	1.9	1.8	1.5	1.9	1.7
19	1.5	1.3	1.4	1.5	1.3	1.3	1.3	1.5	1.4	1.5	1.2	1.7	1.7	1.5	1.6	1.8	1.7	1.8	1.9	2.0	2.0
20	1.3	1.2	1.3	1.3	1.0	1.5	1.2	1.5	1.3	1.3	1.4	1.4	1.7	1.6	2.0	1.3	2.0	1.9	1.8	1.8	1.6
21	1.4	1.2	1.2	1.3	0.9	1.3	1.1	1.5	1.2	1.3	1.3	1.3	1.5	1.5	1.5	1.4	1.7	1.8	1.7	1.9	1.7
22	1.4	1.5	1.4	1.4	1.3	1.3	1.3	1.5	1.3	1.4	1.4	1.5	1.4	1.6	1.8	1.7	1.8	1.7	1.8	1.8	1.8
23	1.7	1.7	1.8	1.5	1.4	1.5	1.7	1.7	1.5	1.5	1.4	1.4	1.3	1.4	1.6	1.4	1.4	1.8	1.5	1.6	1.3
24	1.2	1.1	1.1	1.3	1.0	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.4	1.4	1.7	1.6	1.6	1.5	1.7	1.7	1.5

Series of 8-foot rows	Row Number 22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
1	2.0	1.8	2.0	1.8	1.8	2.0	2.1	1.9	1.9	1.7	1.6	1.8	1.8	1.6	1.8	1.8	1.6	1.5	1.6	1.6	1.6
2	2.0	2.0	2.1	1.9	1.9	1.9	1.9	1.7	1.8	1.9	1.9	1.9	1.8	1.7	2.0	1.8	1.7	1.7	1.6	1.8	1.6
3	2.0	1.8	2.1	1.8	1.9	1.8	2.0	1.8	1.9	1.9	2.0	1.6	2.0	1.9	1.9	1.7	1.8	1.9	2.0	1.8	1.9
4	1.9	2.0	2.0	2.0	1.4	1.6	1.8	1.5	1.7	2.0	1.8	2.0	1.8	1.8	1.9	1.7	2.0	1.7	1.8	1.9	1.6
5	1.8	1.7	1.6	1.9	1.5	1.5	1.5	1.8	1.6	1.8	2.0	1.8	1.8	1.9	1.7	1.7	1.7	1.7	1.5	1.7	1.5
6	1.9	1.9	2.0	2.0	1.5	1.7	1.7	1.8	1.3	1.9	2.0	1.8	1.9	1.7	1.7	2.0	1.8	1.8	1.5	1.8	1.7
7	2.0	2.0	1.9	2.0	1.1	1.8	1.9	1.7	1.5	2.0	1.9	1.9	1.5	1.9	1.9	2.1	2.1	2.0	1.6	2.0	1.7
8	1.9	1.9	2.0	1.8	1.6	1.7	1.6	1.6	1.9	2.1	2.1	2.1	1.7	1.7	2.0	2.1	2.0	1.9	1.9	2.0	1.4
9	1.7	2.0	2.0	1.9	1.6	1.6	1.8	1.7	1.9	1.8	2.0	2.1	1.7	2.0	2.1	2.0	2.2	2.2	1.8	1.9	1.4
10	2.0	2.0	1.9	1.8	1.7	1.7	1.6	1.8	1.7	2.2	1.8	2.1	1.6	1.5	1.7	1.9	2.0	2.0	1.8	1.9	1.6
11	1.7	2.0	2.0	1.9	1.7	1.6	1.9	1.6	1.8	1.9	2.3	2.0	1.5	1.7	2.0	1.8	2.1	1.9	1.8	1.8	1.7
12	2.0	2.6	2.0	2.0	1.5	1.9	1.8	1.8	2.0	1.9	2.1	2.0	1.8	1.7	1.9	2.2	2.5	2.3	2.0	2.0	1.8
13	1.8	2.1	2.0	2.0	1.6	1.6	1.6	1.8	1.7	1.9	2.1	1.7	1.7	1.6	1.9	2.1	2.0	2.1	2.0	2.0	1.9
14	2.2	2.1	1.9	1.9	1.6	1.5	1.5	1.8	2.0	2.0	2.0	1.9	2.0	1.9	2.2	2.0	1.9	2.2	2.2	2.0	2.2
15	2.0	2.0	1.9	1.8	1.3	2.0	1.9	1.9	1.9	2.1	2.0	2.2	2.0	2.0	2.1	2.1	2.0	2.1	2.0	2.2	2.2
16	1.8	2.0	1.9	2.2	1.9	1.2	2.1	1.9	2.0	2.0	2.0	1.8	1.9	1.9	2.1	2.1	2.1	2.0	2.1	2.0	2.2
17	1.9	2.1	2.0	2.2	1.6	2.1	2.2	1.8	1.9	2.0	2.3	2.1	2.0	2.1	1.9	2.3	2.2	2.4	2.2	2.4	2.0
18	2.0	2.3	1.7	2.0	1.9	1.6	2.0	1.8	1.9	1.9	2.1	1.9	1.8	1.9	2.0	2.3	2.2	2.1	2.1	2.1	1.8
19	2.2	2.1	1.9	2.1	1.8	1.7	2.3	1.6	2.0	1.8	2.4	1.9	2.0	1.9	2.1	2.0	1.8	1.8	1.9	1.5	2.0
20	2.0	2.0	2.0	1.8	1.5	1.6	1.7	1.4	1.8	1.8	2.0	2.0	1.9	1.9	2.0	2.1	2.0	1.9	1.6	2.6	1.7
21	1.9	1.9	1.9	1.8	1.9	1.8	2.0	1.8	1.9	1.8	2.1	1.8	2.1	2.0	1.9	2.2	1.9	1.9	1.8	1.9	1.9
22	1.8	1.9	1.8	1.8	1.7	1.7	1.8	1.6	1.8	1.7	1.9	2.1	2.0	1.9	1.7	1.7	1.9	1.7	1.9	1.8	1.7
23	1.7	1.7	1.7	1.6	1.6	1.8	1.7	1.6	1.6	1.8	1.8	1.8	1.9	1.7	1.5	1.4	1.3	1.3	1.4	1.5	1.4
24	1.4	1.7	2.0	1.5	1.3	1.7	1.3	1.7	1.8	2.0	1.9	2.0	1.7	1.8	1.7	1.3	1.3	1.7	1.5	1.7	1.5

TABLE 2.—*Yield of soybean seed in bushels per acre for each 8-foot section of row in 1926.*
(Yields recorded to nearest bushel.)

Series of 8-foot rows	Row Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	22	23	22	17	21	19	20	22	22	20	19	23	20	21	19	24	22	19	19	19	22	21	17	17	18	21	21
2	25	26	23	21	24	21	21	18	20	21	21	22	22	21	20	20	22	19	21	21	20	20	21	22	20	23	19
3	21	21	22	22	23	22	22	26	25	23	22	25	23	19	23	23	21	21	22	20	21	22	21	25	23	25	22
4	19	18	21	19	18	19	22	24	22	24	23	22	21	23	20	22	19	21	19	17	20	18	18	20	19	24	19
5	19	21	21	20	18	18	17	18	21	24	25	22	21	17	19	19	23	21	17	17	19	19	17	20	18	21	22
6	20	22	18	16	15	15	15	19	18	17	20	22	18	18	18	23	18	18	19	20	19	19	19	22	26	27	27
7	23	22	17	16	14	16	16	19	17	19	17	18	19	17	16	20	15	19	18	20	20	18	20	22	23	24	22
8	23	20	17	18	17	18	17	25	25	25	26	25	19	18	17	16	16	16	15	18	21	22	22	22	24	22	26
9	21	21	18	17	18	17	19	21	24	24	27	23	19	21	18	21	16	19	18	17	23	18	21	22	21	24	27
10	20	15	14	16	14	16	14	23	22	26	22	20	17	16	16	18	19	19	19	18	18	19	20	19	19	25	21
11	19	18	16	14	16	16	14	21	21	21	20	18	17	16	15	18	18	22	19	16	20	18	19	19	19	22	21
12	15	12	13	15	16	15	18	20	21	22	19	19	17	16	17	20	18	18	18	19	20	18	20	19	22	22	24
13	15	15	18	16	17	17	17	23	22	22	22	21	18	17	17	18	17	18	16	17	19	20	18	18	22	25	21
14	29	18	20	15	16	15	18	22	20	23	19	19	17	18	15	17	17	18	16	16	20	19	23	21	27	25	24
15	22	21	19	19	16	16	19	17	21	22	18	19	19	19	18	19	16	16	15	22	21	19	19	20	25	23	20
16	18	21	26	17	13	18	15	15	18	19	18	17	17	17	17	21	15	16	13	16	22	19	18	22	22	22	17
17	21	20	23	17	15	17	19	20	18	22	21	17	20	18	17	19	17	13	13	16	19	15	19	20	19	19	20
18	20	22	21	20	17	16	17	20	20	21	21	17	19	22	19	23	19	17	14	21	25	20	20	20	23	22	21
19	22	26	23	17	16	18	14	19	17	18	18	17	17	21	20	18	16	16	13	21	22	18	20	20	21	18	19
20	19	23	21	17	17	16	17	19	17	24	24	19	21	18	23	21	19	19	18	19	23	22	21	23	21	23	20
21	25	24	24	22	20	20	22	19	20	23	21	23	22	16	17	16	20	17	20	24	27	25	24	27	26	26	26
22	22	23	22	19	15	16	16	18	17	22	20	18	19	16	14	18	18	17	19	19	24	23	22	24	25	22	20
23	24	23	21	20	17	17	17	17	18	20	21	18	17	16	17	19	19	16	17	18	20	19	20	19	21	22	22
24	24	26	21	21	15	19	17	22	16	19	19	18	18	21	17	19	17	15	16	17	19	17	18	19	20	21	16
25	22	23	22	21	15	18	18	18	19	20	20	18	20	21	20	20	21	18	18	22	24	21	20	22	20	19	17
26	24	26	26	21	19	16	19	17	19	18	17	19	17	18	19	20	19	17	14	20	21	19	17	19	19	21	20
27	26	28	22	21	20	18	18	19	18	20	18	18	18	18	17	19	18	15	15	18	19	19	17	19	18	19	18
28	19	21	20	20	20	17	20	20	21	19	18	18	17	18	17	20	19	18	17	18	20	20	19	20	20	20	16

Series of 8-foot rows	Row Number 28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55
1	22	18	23	20	22	21	21	22	21	20	19	20	20	21	21	23	25	27	23	21	24	25	27	25	24	25	24	27
2	22	22	23	20	22	20	20	20	16	17	18	20	20	23	21	19	21	18	19	19	18	17	18	18	19	20	17	20
3	28	20	23	24	26	24	20	22	23	25	25	26	26	22	26	22	23	19	20	21	19	18	19	17	19	20	16	18
4	21	20	19	21	24	20	19	22	22	22	25	24	23	22	22	23	24	24	24	24	23	24	24	21	21	20	19	20
5	21	21	19	21	20	19	19	20	20	18	22	23	21	22	23	22	20	25	24	24	23	21	24	24	21	22	23	23
6	24	22	23	18	20	20	19	22	21	19	20	22	20	19	21	21	20	22	23	19	23	23	23	26	22	25	20	22
7	27	27	27	25	24	20	17	23	20	17	19	21	19	22	20	21	22	22	22	22	24	22	24	19	22	23	25	22
8	25	23	24	22	21	18	20	19	14	17	17	19	21	21	24	24	28	23	22	21	21	20	20	21	22	21	22	19
9	24	25	22	26	20	20	19	18	16	18	18	21	20	21	27	23	19	19	18	21	18	18	22	18	24	22	20	20
10	25	22	23	23	20	17	15	17	16	17	17	16	21	17	21	20	16	18	18	19	18	17	16	19	20	21	19	21
11	22	20	21	22	20	16	17	16	15	16	18	14	15	18	18	18	21	16	16	18	21	16	20	15	23	17	20	18
12	20	22	21	22	22	22	17	15	13	14	17	15	20	20	20	17	18	19	16	15	19	15	18	17	22	21	21	19
13	19	20	22	21	22	22	18	19	18	18	16	16	17	21	18	20	19	19	18	20	19	18	15	17	19	19	21	17
14	19	24	19	22	24	23	19	20	21	18	16	20	22	18	21	19	23	19	21	18	19	18	17	18	21	21	20	16
15	20	20	23	20	24	20	20	21	18	18	18	19	21	20	19	18	19	20	19	20	24	20	23	23	23	23	22	19
16	15	17	20	21	22	21	17	18	19	13	17	16	18	16	22	18	19	21	23	21	27	21	22	23	24	20	23	19
17	19	17	16	20	23	20	21	15	16	13	15	18	19	18	27	23	22	20	20	22	26	17	21	22	24	20	23	20
18	22	21	25	23	23	22	25	24	21	20	16	19	21	23	24	27	22	23	24	17	24	20	23	26	24	25	21	23
19	19	19	20	24	23	22	23	20	19	20	17	19	22	23	20	21	18	18	21	18	22	20	18	17	22	23	19	18
20	19	22	22	21	22	19	17	17	18	19	17	19	19	20	20	19	18	17	17	19	24	22	18	17	22	21	17	22
21	24	26	23	26	25	19	21	23	21	16	20	19	20	19	22	19	21	19	21	17	23	21	21	15	17	21	18	24
22	24	23	22	23	22	20	19	20	17	14	18	17	19	16	18	18	17	19	18	19	20	22	20	16	19	18	19	15
23	23	21	19	18	21	17	20	19	14	18	18	17	17	18	21	21	21	23	23	22	23	24	19	21	21	20	21	19
24	17	19	16	20	18	17	16	16	18	15	15	14	18	18	22	26	22	23	22	20	22	22	22	21	20	18	21	20
25	18	20	21	22	20	18	19	17	20	16	21	18	17	19	19	21	19	20	23	19	21	20	22	19	21	21	19	22
26	20	17	20	16	21	19	19	19	17	19	18	18	17	17	20	19	22	21	21	24	19	20	18	20	17	19	22	17
27	18	20	19	21	20	23	21	21	20	24	21	21	21	21	21	21	22	22	24	21	26	20	21	22	22	22	20	21
28	20	17	20	16	21	15	21	20	21	20	21	22	22	24	25	27	25	26	20	24	23	21	22	20	21	22	21	19

In 1925 there were 42 rows each 200 feet in length and in 1926 there were 55 rows each 232 feet in length. In both years border rows were grown and discarded before the remaining rows were harvested. Each year the rows were harvested in 8-foot units and the yields for each of these 8-foot plats determined. In 1925 there were 1,008 such individual plats harvested and their yields computed and in 1926 there were 1,540 plats.

In obtaining the forage yields the plants from each 8-foot plat were placed in burlap bags and weighed after being thoroughly dried. The method of drying samples followed at the West Virginia station has been described in a previous paper.[3] For obtaining the seed yields the plants from each plat were also placed in burlap bags and then threshed and weighed after becoming dry.

The soil type on which these tests were located is classified as Dekalb silt loam. This soil is typical of much of West Virginia.

The 8-foot plats were numbered in such a way that consecutive plats of this size could be combined to make up plats consisting of 16 feet of row, 24 feet, and the various other lengths of row used. Thus, in 1925, there were 1,008 plats 8 feet in length, 504 of the 16-foot plats, 252 of the 32-foot plats, and similarly various numbers of the other sizes. In like manner there were in 1926, 1,540 of the 8-foot plats, 770 of the 16-foot plats, and smaller numbers of longer rows.

The yields of the 8-foot plats harvested for forage in 1925 are given in Table 1, recorded to the nearest first decimal place. Only one decimal place is given in this table since the yields were placed in classes differing by 0.1 ton in computing the statistical constants. In the first horizontal row of figures or in series number one of the 8-foot plats are located plats 1 to 42, in series two are plats 43 to 84, and so on for the remainder of the table.

In computing the statistical constants for the various sizes of plats in 1925 the yields of the different row lengths were grouped into populations of 84 variates each. This number was chosen as a convenient one to handle with the particular number of plats in the study, and at the same time it was felt that this number would be large enough to give reliable figures. Thus, in 1925, there were 12 series of 8-foot plats with 84 variates in each, 6 series of 16-foot plats, 4 series of 24-foot plats, 3 series of 32-foot plats, 2 series of 48-foot plats, and 1 series each of 64-, 80-, and 96-foot plats. The plats in series 1 and 13 of the 8-foot rows were combined to make

[3]GARBER, R J., and ODLAND, T. E. Influence of adjacent rows of soybeans on one another. Jour. Amer. Soc. Agron., 18:605–607. 1926.

one population of plats of this size. In the same way series 2 and 14, 3 and 15, and so on were combined until the 12 series of 8-foot plats were made up. In like manner 84 variates were obtained for each series of the various other sizes of plats used.

The yields of the 8-foot plats in bushels of seed per acre in 1926 are given to the nearest whole bushel in Table 2. The data were handled in the same way as in 1925 in obtaining the yields for various sizes of plats. In this year, however, 110 variates were used for each population, since there were 55 rows grown. The additional length of the rows also made it possible to make up a population of 112-foot rows in addition to the various lengths of row used the previous year.

In these studies the standard deviation has been used in all calculations as the measure of variability.

SIZE OF PLATS

1925 RESULTS

The means and standard deviations of the yields of different series of plats of various row lengths for 1925 are given in Table 3.

TABLE 3.—*Means and standard deviations for the various lengths of row of soybeans harvested for hay in 1925.*

	8-foot rows			16-foot rows	
Series	Mean	Standard deviation	Series	Mean	Standard deviation
1	1.806±0.013	0.178±0.009	1	1.779±0.012	0.162±0.008
2	1.804±0.015	0.204±0.011	2	1.686±0.018	0.251±0.013
3	1.699±0.021	0.283±0.015	3	1.663±0.021	0.283±0.015
4	1.714±0.019	0.256±0.013	4	1.671±0.019	0.258±0.013
5	1.694±0.022	0.304±0.016	5	1.652±0.018	0.238±0.012
6	1.682±0.021	0.286±0.015	6	1.618±0.018	0.241±0.013
7	1.715±0.020	0.278±0.014	Average	1.678±0.007	0.239±0.005
8	1.686±0.021	0.289±0.015			
9	1.676±0.021	0.292+0.015			
10	1.651±0.018	0.244±0.013			
11	1.633±0.016	0.219±0.011			
12	1.644±0.023	0.311±0.016			
Average	1.700±0.006	0.262±0.004			
	24-foot rows			32-foot rows	
1	1.771±0.014	0.185±0.010	1	1.743±0.014	0.187±0.010
2	1.696±0.019	0.258±0.013	2	1.686±0.018	0.250±0.013
3	1.696±0.019	0.260±0.014	3	1.644±0.016	0.211±0.011
4	1.646±0.016	0.221±0.012	Average	1.691±0.009	0.216±0.007
Average	1.702±0.009	0.231±0.006			
	48-foot rows			64-foot rows	
1	1.727±0.015	0.207±0.011	1	1.719±0.016	0.211±0.011
2	1.661±0.017	0.237±0.012			
Average	1.694±0.011	0.222±0.008			
	80-foot rows			96-foot rows	
1	1.713±0.015	0.202±0.011	1	1.688±0.015	0.199±0.010

The means for the 8-foot plats varied from 1.633 ±0.016 to 1.806 ± 0.013 tons per acre and the standard deviations from 0.178 ±0.009 to 0.311 ±0.016 ton per acre. The average mean is 1.700 ±0.006 and the average standard deviation 0.262 ±0.004. As the figures in Table 3 indicate, there was considerable variation in both statistical constants when this size of plat was used.

The means for the 16-foot plats varied from 1.618 ±0.018 to 1.779 ±0.012 tons and the standard deviations from 0.162 ±0.008 to 0.283 ±0.015 ton. The average mean is 1.678 ±0.007 and the average standard deviation 0.239 ±0.005. These figures show that by increasing the size of plat from 8 to 16 feet the variation in the means as well as in the standard deviations was reduced.

The difference in the average standard deviation for the 8-foot plats and the 16-foot plats is 0.023 ±0.006. This difference is nearly four times its probable error and therefore can be considered as significant. In increasing the size of plat from 8 feet to 16 feet the variability in the yields was significantly reduced.

By increasing the size of plat from 16 to 24 feet the average standard deviation is reduced from 0.239 ±0.005 to 0.231 ±0.006, or a reduction of 0.008 ±0.008. As measured by the probable error the reduction in variability secured by increasing the plats to 24 feet from 16 feet is not large enough to be significant.

An inspection of the figures also shows that there is no reduction in variability as measured by the standard deviation when the length of row is increased from 16 feet to 32 feet, 48 feet, or 64 feet. A reduction of 0.037 ±0.012 in the standard deviation is obtained when the length of row is increased from 16 to 80 feet. This may be considered a significant, although a small, decrease in variability. A slightly greater reduction in the standard deviation is obtained by increasing the size of plat to 96 feet of row.

From these data it would seem that when soybeans are harvested for forage there is no advantage in increasing the size of plat beyond 16 feet unless rows at least 80 feet in length be used. The decrease in variability obtained by using plats 80 or more feet in length is probably not large enough to justify the extra work and the necessary additional land.

1926 RESULTS

In 1926, when the crop was harvested for seed, there were 14 series of 8-foot plats, 7 series of 16-foot plats, 4 of 24-foot plats, 3 of 32-foot plats, 2 of 48-foot plats, and 1 each of 64-, 80-, 96-, and 112-foot lengths. Each series contained 110 variates.

The means and standard deviations for these various sizes of plats are shown in Table 4.

TABLE 4.—*Means and standard deviations for the various lengths of row of soybeans harvested for seed in 1926.*

Series	8-foot rows Mean	Standard deviation	Series	16-foot rows Mean	Standard deviation
1	20.68±0.16	2.45±0.11	1	19.94±0.14	2.10±0.10
2	19.65±0.17	2.64±0.12	2	20.66±0.15	2.35±0.11
3	20.63±0.20	3.14±0.14	3	19.83±0.13	1.97±0.09
4	21.21±0.16	2.43±0.11	4	20.21±0.17	2.68±0.12
5	20.10±0.16	2.43±0.11	5	19.17±0.15	2.37±0.11
6	20.15±0.17	2.59±0.12	6	18.65±0.14	2.11±0.10
7	21.04±0.20	3.12±0.14	7	19.37±0.15	2.30±0.10
8	19.94±0.19	3.03±0.14	Average	19.69±0.06	2.27±0.04
9	20.04±0.17	2.61±0.12			
10	18.90±0.18	2.77±0.13			
11	18.99±0.14	2.18±0.10			
12	18.79±0.16	2.56±0.12			
13	19.48±0.16	2.45±0.11			
14	19.92±0.17	2.73±0.12			
Average	19.97±0.05	2.65±0.03			
	24-foot rows			32-foot rows	
1	20.36±0.13	2.06±0.09	1	20.43±0.12	1.90±0.09
2	20.43±0.13	2.07±0.09	2	20.13±0.14	2.10±0.10
3	20.29±0.15	2.37±0.11	3	18.99±0.13	2.07±0.09
4	18.86±0.14	2.10±0.10	Average	19.85±0.08	2 02±0.05
Average	19.98±0.07	2.15±0.05			
	48-foot rows			64-foot rows	
1	20.33±0.11	1.67±0.08	1	20.28±0.11	1.73+0.08
2	19.53±0.13	1.98±0.09			
Average	19.93±0.09	1.82±0.06			
	80-foot rows			96-foot rows	
	20.20±0.11	1.72±0.08		19.85±0.10	1.62±0.07
	112-foot rows				
	19.86±0.10	1.61±0.07			

The means for the 8-foot plats ranged from 18.79 ±0.16 to 21.21 ± 0.16 bushels per acre. The standard deviations ranged from 2.18 ± 0.10 to 3.14 ±0.14 bushels. As was the case where the soybeans were harvested for forage, the seed yields showed considerable variation when the crop was harvested in 8-foot units. The average for the means is 19.97 ±0.05 bushels and the average standard deviation is 2.65 ±0.03 bushels.

The means for the 16-foot plats ranged from 18.65 ±0.14 to 20.66 ± 0.15 bushels per acre. The standard deviations for this size of plat ranged from 1.97 ±0.09 to 2.68 ±0.12 bushels. The average standard deviation is 2.27 ±0.04 bushels. These figures show that

the variability among the means and standard deviations of the 16-foot plats is considerably less than among the 8-foot plats.

By increasing the size of plat from 8 to 16 feet the average standard deviation is reduced by 0.38 ±0.05 bushel. This difference is more than seven times its probable error. By increasing the size of plat from 8 to 16 feet of row the variability in the seed yields has therefore been significantly reduced.

Inspection of the figures in the table shows that no significant reduction in the standard deviation is obtained by increasing the size of plat from 16 to 24 feet of row.

By increasing the size of plat from 16 to 32 feet the average standard deviation is reduced by 0.25 ±0.06 bushel. This may be considered a significant decrease in variability and indicates that if the size of plat be increased to 32 feet, less variability in seed yields may be expected than with 16-foot plats. An examination of the figures also shows that by increasing the size of plats to 48, 64, 80, 96, and 112 feet, respectively, there is a continuous reduction in variability as measured by the standard deviation. The greatest amount of reduction in the standard deviation occurs, however, when the length of row is increased from 8 to 16 feet.

The results obtained in 1926 with seed yields agree with those obtained with forage yields in 1925 in that considerably less variation is obtained with 16-foot than with 8-foot plats, but that the decrease in variability obtained by increasing beyond this length of row probably would not justify the additional land and labor necessary.

NUMBER OF REPLICATIONS

After determining what size of plat will be most satisfactory when both accuracy in results and economy in land and labor are considered, the next question is how many replications of this size of plat should be used. In this study the 16-foot plats were used in determining the number of replications necessary.

In making up the various number of replications two methods were used, *viz.*, systematic sampling and random sampling. Systematic replication is ordinarily followed in plat work because it is the more convenient method. However, as has been pointed out by Fisher,[4] a random arrangement of plats is the best method of overcoming possible systematic variability in the fertility of the soil on which the tests are conducted. Both systematic replication and random replications were used in these studies in order to compare the two methods.

[4]FISHER, R. A. Statistical methods for research workers. London, 1925.

The systematic replications were made by taking the plats in a systematic order and in such a way that the replications did not fall in the same row. Thus, in the single replication in the 1925 study, rows 1 to 21 of the first series of 16-foot plats were averaged with rows 22 to 42, respectively, of the fourth series of 16-foot plats and rows 22 to 42 of series one were averaged with rows 1 to 21, respectively, of series four. In the same manner, the second and fifth series and also the third and sixth were averaged, thus making 252 variates of 16-foot plats with one replication. In a similar manner, 168 variates with two replications, 126 variates with three replications, 100 variates with four replications, 84 variates with five replications, and 50 variates with nine replications were obtained.

In 1926 the data for the 16-foot plats were handled in a way similar to that used for the 1925 data. In this year there were 385 variates with a single replication, 256 with two replications, 192 with three replications, 154 with four replications, 128 with five replications, and 77 with nine replications.

In order to facilitate the replication by random sampling the yield of each 16-foot plat was recorded on a small card numbered to correspond with the plat number. All the cards for the one year were then mixed together and placed in one box and the cards for the other year in another box.

Single replications were secured by drawing pairs of cards at random from a box and averaging the yields shown on the two cards. This was continued until all cards had been drawn. All cards were then put back into the box and thoroughly mixed. To secure two replications three cards were drawn at random and the yields averaged. In the same manner drawings were made for three four, five, and nine replications. In this way the same number of variates were obtained for each system of replication, whether by systematic or by random sampling.

1925 RESULTS

The data for 1925 are shown in Table 5. Using the standard deviation as the measure of variability, it is seen that the effect of making one systematic replication of 16-foot plats is to reduce the variability in the yields. The standard deviation is reduced from 0.239 ± 0.005 ton to 0.138 ± 0.004 ton, or a reduction of 0.101 ± 0.006. This difference is more than 15 times its probable error and, therefore, indicates that the variability has been significantly reduced by using a single replication.

With random sampling the standard deviation is reduced to 0.191 ± 0.006 ton, or a reduction of 0.048 ± 0.008. Although the

TABLE 5.—*Means and standard deviations for various replications of 16-foot rows of soybeans harvested for hay in 1925.*

Systematic replication			Random replication		
Replication	Mean	Standard deviation	Replication	Mean	Standard deviation
None	1.678±0.007	0.239±0.005			
1	1.654±0.006	0.138±0.004	1	1.655±0.008	0.191±0.006
2	1.681±0.006	0.119±0.004	2	1.681±0.008	0.160±0.006
3	1.664±0.005	0.089±0.004	3	1.664±0.007	0.124±0.005
4	1.674±0.006	0.091±0.004	4	1.671±0.008	0.119±0.006
5	1.690±0.005	0.074±0.004	5	1.668±0.007	0.089±0.005
9	1.678±0.006	0.067±0.005	9	1.670±0.007	0.073±0.005

reduction in variability here is not as large as in the case of systematic replication, it may still be considered significant.

Inspection of the figures shows that further reduction in variability is secured by increasing the number of replications from one to two and from two to three. However, no further reduction in variability is obtained by increasing the number of replications from three to four with either of the methods used. A gradual reduction in variability is secured by increasing the number of replications from three to five or to nine. The greatest reduction, however, takes place in increasing the replications up to three.

A comparison of the standard deviations obtained for the various systematic replications and those obtained with the same respective number of random replications shows that in all cases the standard deviations obtained with random replication are higher than those obtained with systematic replication. This is especially true with the smaller number of replications. When more were used the differences became relatively less. This indicated that systematic sampling, particularly where a small number of replications were used, did not give a true index of the variability in the field as measured by the standard deviation.

The theoretical standard deviations for the various numbers of replications were also calculated for comparison with the actual results obtained. The curves obtained with the theoretical calculations, random replication, and systematic replication are shown in Fig. 1.

As may be seen in this figure the standard deviations obtained with systematic replication are in all cases somewhat lower than the theoretical. With random replication the standard deviations for one and two replications are somewhat higher than the theoretical, while with more than this number the theoretical and actual correspond very closely.

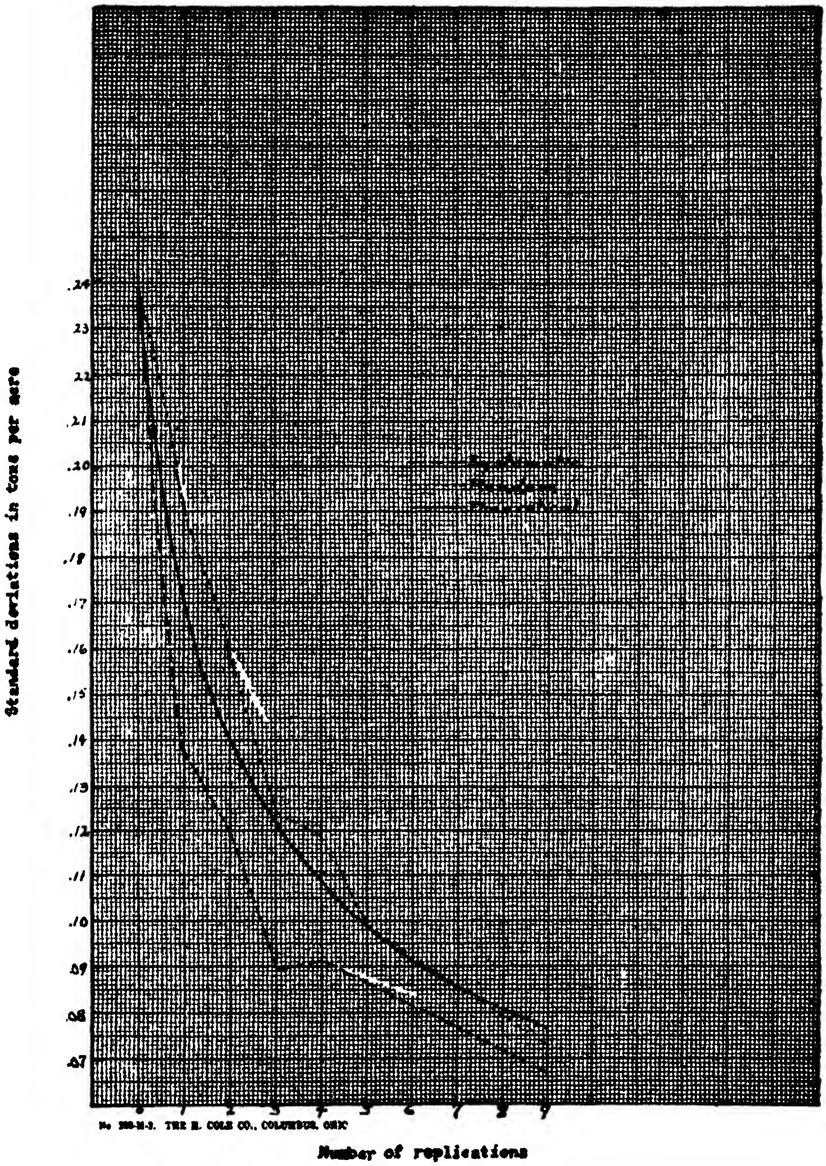


FIG. 1.—Curves showing the theoretical standard deviations, the actual with systematic replication, and the actual with random replication for various numbers of replications used with 16-foot plats of Wilson soybeans grown for hay in 1925.

1926 RESULTS

The data for 1926, when the soybeans were harvested for seed, are given in Table 6. As was the case where the crop was harvested for hay, there is a gradual reduction in variability with an increasing number of replications.

TABLE 6.—*Means and standard deviations for various replications of 16-foot rows of soybeans harvested for seed in 1926.*

Systematic replication			Random replication		
Replications	Mean	Standard deviation	Replications	Mean	Standard deviation
None	19.69±0.06	2.27±0.04			
1	19.43±0.06	1.72±0.04	1	19.44±0.06	1 66±0.04
2	19.69±0.05	1.30±0.04	2	19.71±0.06	1.31±0.04
3	19.58±0.06	1.13±0.04	3	19.57±0.06	1.20±0.04
4	19.71±0 05	1.00±0.04	4	19.66±0.06	1.10±0.04
5	19.59±0.06	0.98±0.04	5	19.61±0.06	1.01±0.04
9	19.71±0.05	0.68±0.04	9	19.62±0.06	0.72±0.04

Where the plats are systematically replicated once there is a reduction in the standard deviation from 2.27 ±0.04 bushels to 1.72 ± 0.04 bushels per acre. This is a difference of 0.55 ±0.06. This difference is approximately nine times its probable error and may therefore be considered as significant. There is also a gradual reduction in the standard deviation as the number of replications is increased from one to two and from two to three. After this number there is no further significant reduction until nine replications are made.

With random sampling there is a significant decrease in the standard deviation from single plats to one replication and from one to two replications. There is, however, no significant reduction in the standard deviation when the number of replications is increased from two to three as was the case when systematic replication was made. When the number of replications is increased to four, five, or nine, there is a gradual decrease in variability. The greatest relative reduction in variability is secured by increasing from single plats to two replications.

The data for 1926 show a close agreement between the standard deviations obtained with systematic and with random replication, indicating that in this year the particular method of systematic sampling used gave a close approximation to random sampling and hence a trustworthy index of the total variability. The standard deviations obtained from systematic and random sampling agree quite closely with those that would theoretically be expected as is shown in Fig. 2.

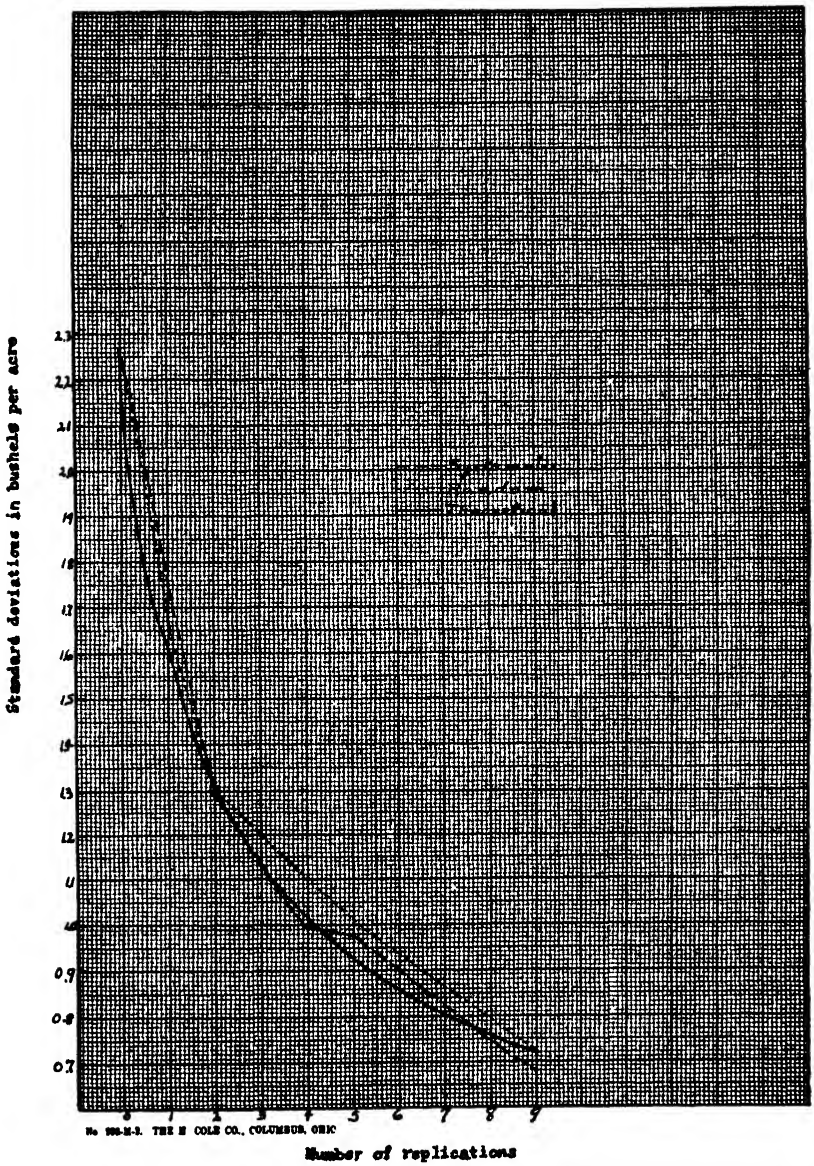


FIG. 2.—Curves showing the theoretical standard deviations, the actual with systematic replication, and the actual with a random replication for various numbers of replications used with 16-foot plats of Wilson soybeans harvested for seed in 1926.

The data obtained in 1926 with seed yields agree in general with the results obtained when the crop was harvested for forage in 1925

in that the use of three replications gives practically as much accuracy as four or five replications. Although using nine replications results in less variability than the use of three replications, the difference probably does not warrant the use of the extra land and labor necessary.

RANDOM vs. SYSTEMATIC SAMPLING

In 1926 a close agreement was obtained between the standard deviations for the same number of replications regardless of whether they were made systematically or at random. In 1925 the standard deviations obtained by systematic sampling, particularly for the lower number of replications, were considerably less than those obtained by random sampling, indicating that in this year and for the smaller number of replications, systematic sampling and the necessary calculation did not give a trustworthy index of the variability in the field. If plat treatments or varieties were compared by means of probable errors calculated from systematic replications similar to those described above, the probable errors would be too small and hence false conclusions might be reached. Systematic replication is usually the more convenient to use in practice. It would seem, then, that a manner of replication which combines some of the more desirable features of both random and systematic sampling is the most practical.

SUMMARY AND CONCLUSIONS

Two years' data were obtained with soybeans grown in cultivated rows and harvested in units so that plats of various sizes could be made up and the effect of size of plat on variability studied. The crop was harvested for forage one year and for seed the other. The effect of replicating the 16-foot plats on the variability of the yields was also studied.

Under the conditions obtaining where these experiments were made it would seem that a 16-foot plat replicated three times will be the most satisfactory when both accuracy in results and economy of land and labor are taken into consideration.

EFFECT OF FERTILIZERS ON MAINTAINING STANDS OF ALFALFA[1]

B. A. Brown[2]

INTRODUCTION

In regions where alfalfa does not thrive unless strict attention is paid to several limiting factors, the problem of maintaining good stands for more than two or three years is an important one. Regardless of whether a long rotation, including several successive years of hay, is an economically sound practice, the fact remains that in the northeastern United States this type of rotation—or lack of rotation—is commonly followed. When a farmer finds that his alfalfa field is growing mostly grasses or weeds the second or third year after he has spent considerable time and money to secure a stand of this valuable legume, he is apt to conclude that some other crop is more suitable for his conditions. Therefore, if the present campaigns to replace grass with alfalfa are to be successful, everything that will help growers to maintain good stands of alfalfa for five or more years should be considered carefully.

In New England it is usually necessary to have a fertile soil, lime liberally, and inoculate thoroughly to secure stands of alfalfa that will go into the *first* winter in thrifty condition. To enable the alfalfa to withstand severe winter weather several practices have been recommended. The use of seed from hardy northern-grown strains has been advocated so widely that it need only be mentioned here. In recent years the results from several well-conducted experiments have demonstrated that cutting when the alfalfa approaches full bloom and the removal of not more than two crops per year reduces the amount of winter-killing appreciably. It has been proved that this is due to the large supply of reserve food which the growing alfalfa stores in its roots as its approaches maturity. Frequent cuttings drain these reserve food supplies and reduce the plant's resistance to adverse conditions. Top-dressing with manure or straw in the fall has been recommended and is, no doubt, a good practice if a sufficient supply of these materials is available. Good surface drainage is also a prime requisite. However, when all of the above-mentioned conditions are favorable, failures to maintain good stands of alfalfa are found. That this may be due to improper or inadequate

[1]Contribution from Department of Agronomy of the Connecticut (Storrs) Agricultural Experiment Station, Storrs, Conn. Received for publication October 31, 1927.

[2]Assistant Agronomist.

TABLE 1.—*Effect of fertilizer treatments on stands and yields of alfalfa.*

Plat No.	Total tons limestone per acre, 1914–19	pH in 1921	CaO requirement, 1924[a]	General manurial treatment per acre[b]	Percentage stands of alfalfa seeded in August, 1923 Grimm Oct. 1923	Grimm Apr. 1924	Grimm Aug. 1925	Common Oct. 1923	Common Apr. 1924	Common Aug. 1925	Total tons hay per acre[c]
2	10	6.7	360	M, 10 tons	90	80	60	90	70	35	5.0
3	10	6.6	360	M, 10 tons SP, 500 pounds	95	95	55	95	85	15	5.6
4	7	6.6	540	M, 10 tons K, 100 pounds	90	90	65	90	75	30	5.1
5	7	6.6	540	N, 150 pounds SP, 500 pounds K, 100 pounds	95	90	40	95	70	30	4.0
6	7	6.3	540	SP, 875 pounds	95	60	35	95	45	30	2.6
7	7	6.7	540	BS, 933 pounds	90	55	20	90	25	25	2.1
8	7	6.4	720	SP, 875 pounds K, 175 pounds	90	95	80	90	80	85	4.9
9	7	6.4	540	SP, 500 pounds	85	30	10	85	25	20	2.0
10	7	6.3	720	SP, 500 pounds	90	75	15	90	50	30	2.9
11	4	5.8	1,120	K, 100 pounds	90	90	40	90	70	45	3.8
12	7	6.4	900	SP, 1,000 pounds K, 200 pounds	95	95	45	95	85	45	4.7

13	7	6.4	810	SP, 1,000 pounds K, 100 pounds	95	95	25	95	75	25	3.7
14	4	5.9	1,080	SP, 500 pounds K, 50 pounds	90	90	20	90	60	15	3.0
15	4	5.9	1,440	SP, 500 pounds K, 100 pounds	90	85	20	90	70	20	3.7
16	5½	6.4	810	BM, 636 pounds	90	80	15	90	60	15	3.0
17	5½	6.4	720	N, 99 pounds SP, 875 pounds	95	90	25	95	70	35	4.2
18	5½	—	1,170	K, 200 pounds	85	90	85	85	50	70	4.1
19	8½	6.6	360	BM, 636 pounds	90	80	20	90	60	25	3.2
20	8½	6.6	360	N, 99 pounds SP, 875 pounds	95	85	15	95	75	20	4.1
21	8½	—	540	K, 200 pounds	80	90	90	80	70	85	5.0
Average all treatments					91	82	39	91	64	35	3.8

[a]Jones method.

[b]Last treatments applied before seeding in 1923. Letters indicate as follows:
M=Manure, BS=Basic slag, SP=Superphosphate (acid phosphate), N=Nirate of soda, K=Muriate of potash, BM=Bone meal.

[c]This includes the total yields of hay, 15% moisture, from two cuttings in 1924 and two cuttings in 1925 (average of both varieties).

fertilization is suggested by the results secured from a series of soil treatment plats at the Storrs (Connecticut) Agricultural Experiment Station. The writer has been unable to find any data in the literature bearing on this point.

The series of plats in question is located on Gloucester fine sandy loam soil in a tile-drained field which slopes gently to the North, providing excellent drainage conditions. Continuous alfalfa has been the rule on these plats since 1914. When a stand became thin, the entire series was plowed, fitted, and reseeded without a nurse crop. However, following the very severe winter of 1917-18 which killed practically all of the alfalfa on the plats, potatoes were grown in 1918 and a cover crop of rye was seeded after the potatoes were dug. The rye was harvested for grain in 1919 and alfalfa seeded at once. Since 1919, no other crop than alfalfa has been grown.

TREATMENT OF PLATS

The manurial treatments, given in Table 1, have been applied just previous to reseeding, usually every third year. Ground limestone was applied at the rate of 4 tons per acre to the entire field in 1914 and most of the plats have received additional applications to bring the totals up to the amounts shown in Table 1. No lime has been applied since 1919 and those plats which have had only 4 tons of limestone have received no lime since 1914. It may be noted that the pH readings of the plats not limed since 1914 were down to 5.8 and 5.9 in 1921 and the CaO requirement from 1,000 to 1,400 pounds per acre in 1924.

As the data secured from this experiment previous to 1923 have been published elsewhere,[3] only the results since that date will be included here. In Table 1 may be found the total tons of limestone applied, the pH readings in 1921, the lime requirements in 1924, the general manurial treatments, and the stands on the variously fertilized plats in 1923, 1924, and 1925 for both Grimm and common alfalfa. The stands given were estimated as accurately as possible but, of course, are subject to the errors in personal judgment which are bound to occur. The differences are so marked in most cases, however, that such errors may be neglected.

In studying the results given in Table 1, the following explanations of the manurial treatments should be kept in mind. Some of the plats have received the "general" treatment several times, others only once. Plats 2, 3, 6, 7, 8, and 9 have been treated as stated since

[3]Brown, B. A., and Slate, W. L. Alfalfa in Connecticut. Conn. (Storrs) Agr. Exp. Sta. Bul. 115. 1923.

1917. Plat 4 received the same amount of superphosphate (acid phosphate) as plat 3 up to 1923, when potash was substituted. Plat 5 has always received a "complete" fertilizer, but usually one carrying less potash and more phosphoric acid than the application given in the table.

Plats 10 to 15, inclusive, have received the stated treatment but once (1923), all receiving manure up to 1920. From 1916 to 1920, plats 10 and 11 had received a total of 60 tons; plats 12 and 13, 33 tons; and plats 14 and 15, 24 tons of manure per acre.

Plats 16 to 21, inclusive, received an application of manure in 1917, a 4-8-4 mixture for potatoes in 1918, and the treatments given in Table 1 in 1919 and 1923. These six plats are comparable with each other, excepting that the last three—duplicates of the first three—received an additional application of limestone in 1919.

DISCUSSION OF RESULTS

To facilitate the discussion of the results, plats receiving the same general treatment will be grouped. Also, no conclusions as to the relation of nitrogen to alfalfa stands will be drawn from these plats, since it is impossible to separate the effects of nitrogenous fertilizers from the more important effects (for alfalfa) of phosphoric acid and potash and, moreover, on well limed, inoculated soil, such as obtained on these plats, it is very doubtful if any advantages would be gained by including nitrogen with the other plant nutrients. In fact, although the evidence is not conclusive, nitrogen, either from manure or nitrate of soda, seems to have reduced the stands of alfalfa on these plats. If it is assumed that the manured plats, whether supplemented or not, represent an NPK treatment and including the NPK treatment from artificial fertilizers, the average stand in 1925 for four NPK plats was 55 and 22% for Grimm and common alfalfa, respectively, whereas, the PK plat (8), which is somewhat comparable to the four averaged above, had corresponding percentages of 80 and 85. The grasses have always been more in evidence on the plats receiving nitrogenous treatments, and this explains the relatively larger yields, with poorer stands of alfalfa, from the manured plats.

EFFECT OF LIME

As all of the plats have been heavily limed, it is not to be expected that very significant differences would be obtained from additional applications. The average stands on plats 16, 17, and 18 with 5½ tons of ground limestone per acre have been practically the same as the entirely comparable plats 19, 20, and 21 with 8½ tons of ground

limestone per acre. Plats 10 and 11 are comparable except for lime and potash and it is evident that the 7 tons of limestone on plat 10 were not as effective in maintaining stands as the 4 tons of limestone plus 100 pounds of muriate of potash on Plat 11. Plats 13 and 15 have been treated in practically the same manner, except that the former has received 3 tons more limestone and 500 pounds more superphosphate (acid phosphate), yet no appreciable differences in the stands of alfalfa have resulted. The outstanding feature of the last two comparisons is that the plats (11 and 15) which had received 4 tons of limestone per acre in 1914 and none since did not seem to have their alfalfa stands reduced by a pH acidity of 5.8 or a lime (CaO) requirement of over 1,000 pounds. These results seem to indicate that for alfalfa liming may be over and other plant nutrients under emphasized.

EFFECT OF PHOSPHORUS

Most of this series of plats has received rather liberal applications of phosphorus carriers, but several comparisons as to the effects of this nutrient are possible. Plats 6, 7, and 9 furnish the best results bearing on this point. Each has been limed alike—7 tons of limestone per acre. Plat 9 has not been treated with *any* fertilizer since 1914, when the entire field received 666 pounds per acre of a 3-10-6 mixture, while plats 6 and 7 have received 630 pounds per acre of phosphoric acid in superphosphate (acid phosphate) and basic slag, respectively. The average percentages of stand for Grimm and common were as follows:

Plat	Treatment	October 1923	April 1924	August 1925
6	Superphosphate (acid phosphate)	95	53	33
7	Basic slag	90	40	23
9	No fertilizer	85	28	15

These figures show that liberal applications of superphosphate (acid phosphate) and basic slag have resulted in a somewhat better stand than obtained on the no-phosphorus plat. Between the two, superphosphate (acid phosphate) has been superior to basic slag. However, neither plat 6 nor plat 7 has produced even fair stands or yields in recent years.

As a supplement for manure, 2,875 pounds of superphosphate (acid phosphate) have been applied to plat 3 since 1917. If the stands on this plat are compared with those on plat 2, which has received the same amount of manure and lime but no superphosphate

(acid phosphate), it will be seen that no consistent improvement in the alfalfa stands have resulted.

Although plats 8, 18, and 21 are not entirely comparable in respect to lime and other treatments previous to 1919, since that date they represent a PK plat (8) and two K plats (18 and 21). The stands for both varieties of alfalfa have high average percentages for all three plats with no appreciable advantage for phosphorus, as follows:

Plat	Treatment	October 1923	April 1924	August 1925
8	PK	90	88	83
18	K	85	70	78
21	K	80	80	88

In the period 1914 to 1919, however, plats 18 and 21 received 234 pounds of phosphoric acid and the possible residual effects of those early applications may have influenced the recent results.

After considering the available comparisons carefully, it would seem that phosphorus has not been of much consequence in maintaining the stands of alfalfa on the field in question.

EFFECT OF POTASH

As the following summary brings out, potash is the one plant nutrient to which the alfalfa has responded markedly.

The effects of as little as 50 pounds of muriate per acre have been plainly evident. The differences between the Grimm and common

	Average percentage stands of alfalfa					
	Grimm			Common		
Treatment	Oct. 1923	Apr. 1924	Aug. 1925	Oct. 1923	Apr. 1924	Aug. 1925
Potash	90	90	52	90	72	42
No potash	91	69	19	91	51	25

varieties have been negligible in comparison with the differences between the plats which have or have not received potash. However, the results indicate that rather high or frequently repeated applications give the most persistent stands of alfalfa. This is brougth out by the 1925 stands on plats 11, 12, 13, 14, and 15 which received their first fertilizer potash since 1915 in 1923. The average percentage stand on those plats the second year after seeding was 30, whereas on plats 8, 18, and 21, which had received rather liberal applications of potash in both 1919 and 1923, the average percentage stand was 83.

Manure as a carrier of potash has not proved as effective as muriate in maintaining alfalfa stands. Theoretically, the 10 tons of manure

per acre applied in 1919 and 1923 to plats 2, 3, and 4 should have contained as much potash as the 200 pounds (less on plat 8) of muriate which plats 8, 18, and 21 received in the same years. Yet the latter group of plats have had considerably better stands the second year after seeding as the following averages show:

Plats averaged	Source of potash	Average percentage stands of alfalfa October, 1923	April, 1924	August, 1925
2-3-4	Manure	92	83	44
8-18-21	Muriate	85	79	83

The stimulating effect of the nitrogen in the manure on the grasses is, no doubt, partly responsible for the poorer stands of alfalfa on the manured plats. Also, the potash in manure is less soluble and, therefore, less readily available and less active than that in the muriate.

The reasons for the marked response of alfalfa to potash have not been determined, but one suggestion is found in the analyses of feeding stuffs in Henry and Morrison's "Feeds and Feeding" (17th edition). There, the average analysis of alfalfa hay is given as 2.23 % potash and 0.54% phosphoric acid, or four times as much potash as phosphoric acid. Although the analyses of plants may not be a reliable criterion for determining how to fertilize the soil for their growth, they do bring out facts which indicate the relative needs of various species for available supplies of plant nutrients. Thus, a 3-ton crop of alfalfa hay must obtain 134 pounds of potash from somewhere. Unless the soil contains a *total* amount of potash large enough to insure a plentiful supply of *available* potash or unless available potash is added in manure and fertilizer, a decrease of vigor, with its dire results, is bound to occur.

It has been stated that potash aids in the synthesis and translocation of starch in plants. This suggests that an optimum supply of available potash in the soil might result in large, strong alfalfa roots, with large amounts of organic reserves, which would enable them to withstand adverse conditions much better than roots not as well fortified in this respect. More work is needed to determine the correctness of this supposition.

SUMMARY

The effect of fertilizers on maintaining stands of alfalfa has received little attention if the scarcity of literature bearing on this point may be taken as a criterion.

The stands and yields of alfalfa for 1923 to 1925 on a series of variously fertilized plats on Gloucester fine sandy loam soil at the Storrs (Connecticut) Agricultural Experiment Station are reported. All of the plats have been limed liberally.

Nitrogenous fertilizers, particularly manure, have increased the total yields but have tended to increase the grasses and weeds and reduce the percentages of alfalfa in the stands.

Carriers of phosphoric acid have given slightly better stands of alfalfa than the no-treatment plat, but no advantages have resulted when superphosphate (acid phosphate) has supplemented manure or potash.

Potash, either from manure or muriate, has been very beneficial in maintaining stands of alfalfa on this field. Of the two, applications of 200 pounds per acre of muriate in 1919 and 1923 were more effective than 10 tons of manure per acre in the same years. The differences in stands between plats receiving or not receiving potash have been much greater than the differences between the Grimm and northern-grown common varieties of alfalfa.

On plats which received 4 tons of ground limestone per acre in 1914 and none since and which gave a pH reading of 5.8 in 1921 and a CaO requirement of over 1000 pounds in 1924, better stands of alfalfa have been obtained by applying 100 or 200 pounds of muriate of potash than by applying 3 additional tons of ground limestone, thereby decreasing the pH acidity to 6.4 and the CaO requirement to 700 pounds.

The reasons for the marked effects of potash on the stands of alfalfa have not been determined. It is suggested that the relatively large percentage of potash in alfalfa and the assistance which potash is supposed to render in the synthesis and translocation of starch in plants may have been responsible. More work is needed on this question.

GROWTH AND DISTRIBUTION OF JAPAN CLOVER IN OHIO[1]

M. V. BAILEY[2]

INTRODUCTION

Japan clover (*Lespedeza striata*), a native of eastern Asia, was introduced into the southeastern part of the United States just previous to 1850 (4).[3] About the time of the Civil War it became fairly well scattered by various means.

At the present time it is growing all over southeastern United States from central New Jersey to central Kansas and from there south to the Gulf of Mexico. Being an annual, its distribution is limited by its ability to produce seed and this, in turn, is apparently limited by the climate or length of growing season. Failures of Japan clover to perpetuate itself are reported from Michigan (13), Iowa (14), and northern Ohio.

Japan clover has a spreading habit of growth where the stand is thin or where soil is low in fertility, but in thick stands it grows more erect. Its small purple flower, not appearing until September in Ohio, prevents confusion of the plant with hop clover and yellow trefoil

In Ohio it grows from 5 to 10 inches high, depending on soil fertility and weather conditions. Seed is produced plentifully where the season is long enough.

Japan clover is reported (1,2,3,5, 7,8, 9, 10, 11, 12, 15, 16) to be growing on a great variety of soils but does not seem able to grow in pure sand. It grows better where well supplied with water, but is able to continue growth during exceedingly dry, summer weather.

Japan clover cross inoculates with a large group of legumes, including cowpeas, partridge pea, tick trefoil, and peanut. Consequently, artificial inoculation does not usually seem to be necessary.

Growth large enough for hay crops is produced only in Alabama, Mississippi, Louisiana, Arkansas, and western Tennessee. Wherever it grows it furnishes very desirable pasture for which use it serves its best purpose.

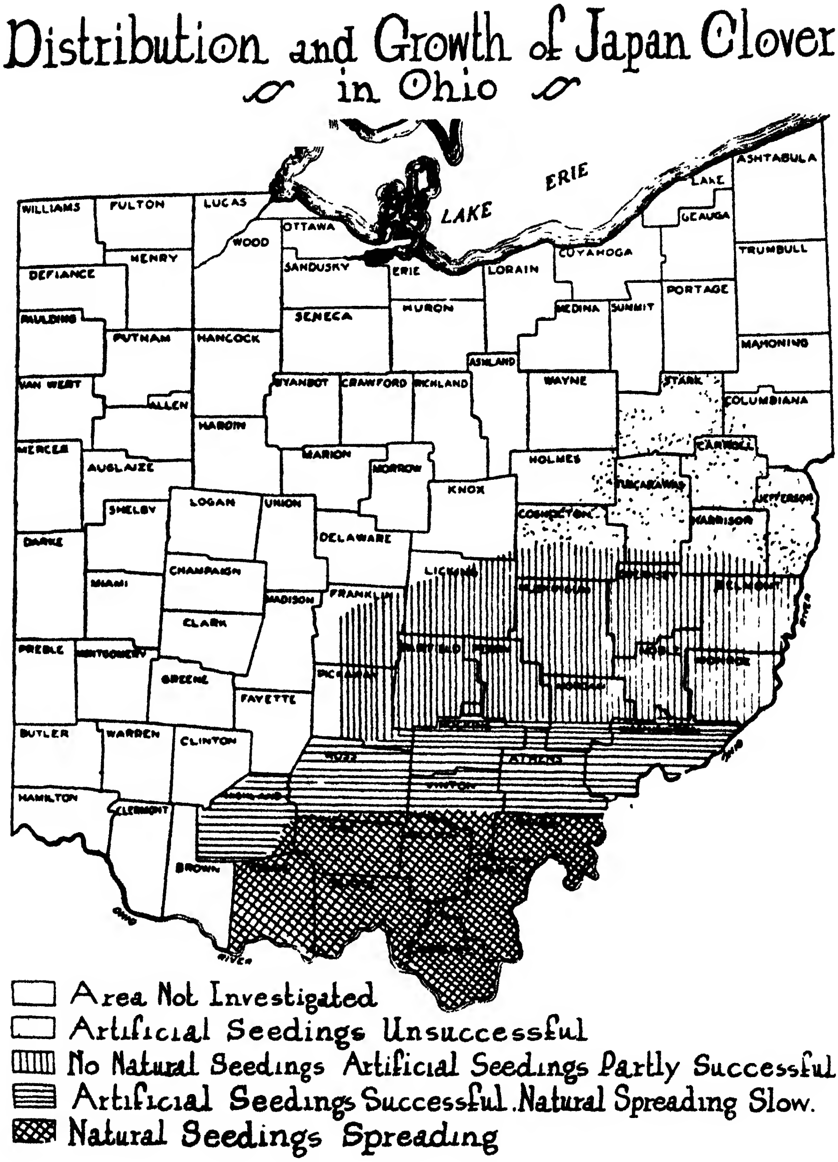
Feeding tests by Henry and Morrison (8) proved it to be fully equal to red clover and nearly as valuable as alfalfa for cattle and horses.

Its value as a soil improver varies with the amount of growth it makes, but its ability to add some nitrogen and organic matter to

[1]Contribution from the Department of Soils of the Ohio State University, Columbus, Ohio. Received for publication November 4, 1927.

[2]Assistant Professor of Soils.

[3]Reference by number is to "Literature Cited," p. 122.



the soil, even in fields badly eroded and very low in fertility, makes it an important legume.

No very large amount of work has been reported on the soil requirements of Japan clover, but its ability to grow on thin eroded pasture fields and abandoned areas is well demonstrated in many states. It has spread naturally over a large area, thriving without any treatment where other crops of economic value have failed.

A number of investigators (1, 2, 4, 10, 16) report varying responses to lime. The general conclusion is that it will grow in most places without lime but applications of lime invariably increase the yield.

Very small to extremely large increases in yield resulting from applications of phosphatic fertilizers have been reported (1, 2, 4, 6, 7, 10, 15).

PRESENT INVESTIGATION

The objects of the present investigation of Japan clover were (a) to determine by observation and correspondence just how widely the plant is distributed in Ohio, either by natural or artificial seeding; (b) to determine the extent to which the growth of the plant is correlated with the acidity as denoted by the pH value, the available phosphorus content, and the type of soil; and (c) to determine the extent of correlation between the protein, total ash, and calcium content of the stems and leaves of the plant with the pH value of the soil in which it grows.

METHODS EMPLOYED

The soil was sampled and its type determined at the same time the growth of the plant in the field was observed. The samples of stems and leaves of the plant were secured from pasture fields in Meigs, Morgan, Jackson, and Scioto Counties, small cages being erected to prevent livestock grazing.

The pH value was determined electrometrically, using the quinhydrone electrode. The available phosphorus content was measured by the coeruleomolybdate method. The calcium was determined by precipitation as the oxalate. Nitrogen was determined by the modified Gunning method.

RESULTS

One hundred and seventy soil samples representing 15 different types were collected from 14 counties and the investigation as a whole included 30 counties. (See map.) The analyses of the stems and leaves are given in Table 1.

TABLE 1.—*Analysis of stems and leaves on dry basis.*

County	pH value of soil	Date harvested	Total ash %	Calcium %	Nitrogen %	Protein %
Meigs.....	4.86	July 10	7.30	1.10	2.83	17.68
	4.86		7.65	1.05	2.83	17.68
Scioto.....	4.90	July 8	6.05	1.15	2.82	17.62
	4.93		6.33	1.15	2.83	17.68
Morgan...	5.05	Aug. 18	16.05	0.84	2.74	17.12
	5.03		16.12	0.82	2.76	17.25
Jackson....	5.12	July 19	10.40	0.79	2.87	17.93
	5.13		10.18	0.78	2.88	18.00

The most acid sample had a pH value of 4.43 and the most alkaline sample a pH of 7.73.

Even though some of the soils had been limed, only 25.9% had a pH value of 6.00 or more, 45.9% having a pH between 5.00 and 6.00, and 28.2% having a pH below 5.00.

As was to be expected with soils from the area investigated the content of available phosphorus was low, 71.2% of the samples containing so little available phosphorus that the test did not indicate its presence, while 25.2% contained a low amount, 1.8% contained a medium amount, and 1.8% were high in available phosphorus.

The distribution and growth of Japan clover in the area investigated is shown on the map of Ohio. The experience of farmers with the plant and the observations of the writer were the only guides in preparing the map. Certain discrepencies may appear in it, but in the main the areas shown represent the spread of the plant in the state.

Needless to say, the lines of demarkation between the different areas are not as sharply defined as they are shown on the map. In some cases areas are limited by county lines because no information was secured from the adjoining counties. It is very likely that a study of the plant in southwestern Ohio would show that the different areas could all be extended to the west and south to the western border of Ohio.

SUMMARY

1. The distribution of Japan clover is not limited in Ohio by the acidity of the soil even though lime applications increase its growth. No soils were sampled which were acid enough to prevent its growth.

2. The available phosphorus content of the soil seems to affect the growth of Japan clover more than acidity. In every case where phosphate fertilizers had been applied the growth had noticeably increased.

3. As it has spread in Ohio, Japan clover has come into the permanent pasture land first rather than into the meadows on cultivated land.

4. In no place in Ohio was Japan clover found growing large enough to make it a profitable hay crop.

5. In the extreme southern part of the state the growth and distribution of Japan clover seems to be limited by the spread by natural distribution of the seed, while farther north its distribution is largely limited by artificial seedings and length of growing season. Many failures to reseed in the northern counties of the area investi-

gated were on good soils such as are producing good growth of clover farther south.

6. Artificial inoculation of Japan clover does not seem to be necessary. Very few uninoculated plants were found.

7. Japan clover was found growing on practically all the important soil types of the area investigated.

8. There is apparently no correlation between the pH value of the soil and the total ash of the stems and leaves of Japan clover. There is a tendency for the total ash to increase with the maturity of the plant which is contrary to the trend in most plants.

9. The calcium content of the stems and leaves of Japan clover is not closely correlated with the pH value of the soil on which the plant is growing.

10. The percentage of nitrogen and protein content of Japan clover is apparently more dependent on the stage of maturity of the plant than on the degree of acidity of the soil.

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FARM TRIALS OF ARTIFICIAL MANURE[1]

W. A. ALBRECHT AND E. M. POIROT[2]

In consequence of the universally recognized value of barnyard manure and its decreased supply through motorization of farming, attention has turned toward its artificial production. The various farm wastes offer plenty of materials. The burning of wheat straw after the header or thresher, the rotting straw pile occupying valuable ground while its bulk is reduced to a few loads of almost worthless manure, or cornstalks that may need special mechanical handling in consequence of a threatening borer, all invite some artificial manure making process. This is particularly the case in regions where barnyard manure production is least extensive.

Interest has developed in artificial manure making as a result of the work of Hutchison and Richards (2)[3] of England, who have given the essential requirements for this process. Their method, however, is too laborious and requires too much attention to fit itself readily into the American extensive farming scheme, notwithstanding its feasibility for the market gardener or intensive farmer for whom manure has a much higher value. In view of these conditions and after study and trials of the process, some work was begun in the summer of 1926 to adopt, if possible, the artificial manure making process to general farming conditions in the Middle West.

PLAN OF PROJECT

The process when applied to straw demands in the main (a) moisture, (b) a source of soluble nitrogen, and (c) neutral or alkaline conditions. With these requisites in mind, plans were made (a) to design a chemical reagent fulfilling the last two requirements, but of such simplicity that its constituents might be obtained readily and combined on the farm; (b) to mix this material with the straw by applying it through the thresher; and (c) to test the possibility of depending on the rainfall to supply and maintain the needed moisture. The production and use of artificial manure in a farm trial were undertaken on a large farm in Lawrence County, Missouri.

REAGENT USED

Since straw contains a large percentage of cellulose which serves as energy material for certain micro-organisms but is deficient in

[1]Contribution from Soils Department, University of Missouri, Columbia, Mo. Received for publication November 10, 1927.

[2]Associate Professor and Graduate Student, respectively.

[3]Reference by number is to "Literature Cited," p. 132.

nitrogen or growth-producing substance, the reagent was designed to supplement the straw in such a way as to fulfill the requirements of the bacterial medium for cellulose fermentation as suggested by Omelianski (4).

Ammonium sulfate was used to supply the nitrogen. Limestone in the common 10-mesh, agricultural form was used with a view of maintaining neutrality. Superphosphate (acid phosphate) was incorporated in the formula to add phosphates to the manure. In addition, small quantities of magnesium sulfate and ordinary salt were put into the mixture, leaving the other requirements of the micro-organisms to be supplied by the straw. The mixture included 45 pounds ammonium sulfate, 30 pounds limestone, 15 pounds superphosphate (acid phosphate), and 5 pounds each of magnesium sulfate and sodium chloride per 100 pounds. This, used at the rate of 150 pounds per ton of straw, added nitrogen at the rate of 0.7%, or about 14 pounds per ton, the concentration suggested by Hutchison and Richards(2) as necessary to favor decay.

For economic reasons it seemed desirable to reduce this item, which is suggested as a possibility in the work of Halverson and Torgeson(1), in order to guard against a loss of nitrogen. The importance of the phosphate, magnesium sulfate, and common salt may be over emphasized by their amounts; but since the phosphates are not easily lost from and are deficient in manure, a fairly liberal quantity was used. The importance of the last two items of the reagent is being determined in some further work now under way which, to date, indicates that they may be omitted.

APPLYING THE CHEMICALS TO THE STRAW

Under farm conditions where straw accumulates as waste, the quantities are too large to permit much labor in working them over into artificial manure. Consequently, an attachment was fitted to the thresher designed to feed the reagent into the straw while passing through to the stack. This consisted of one section of a fertilizer distributor carrying a hopper and a shaft with a pulley driven by a belt from one of the straw rack shaker shafts. To adjust this to deliver the chemicals at the rate of 150 pounds per ton, the pounds of straw per bushel of grain were determined. The chemicals were then supplied at such a rate per bushel of threshed grain as to provide the proper amount per ton.

TRIALS OF 1926

Three piles of straw were made on July 30. The first one (No. 1) was given the chemicals during threshing, while water from a nearby

creek was delivered to the stack through a fish-tailed nozzle located at the end of the blower pipe and connected by a hose to a centrifugal pump driven from the blower shaft. No effort or particular attention was given to stacking the straw. It was merely left to accumulate until the pile contained about 20 tons and had a height of about

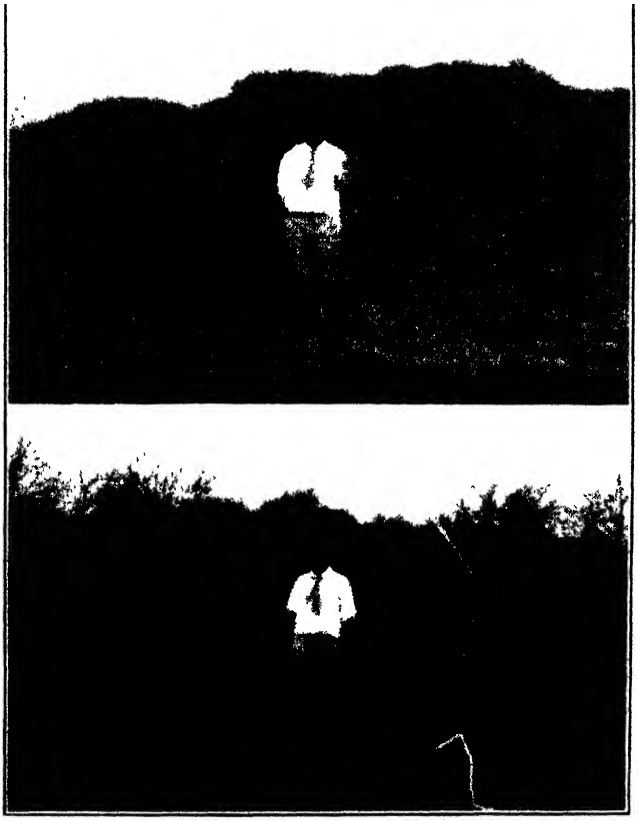

Fig. 1.—Straw pile given no chemicals (above) compared with that receiving chemicals (below). December, 1926.

16 feet. Another pile (No. 2) was threshed in the same manner as No. 1, save that the water was omitted, and at the finish, the top of the pile was levelled so as to make it receptive to rainfall. This pile was intended to determine whether the rainfall would supply the water to initiate and maintain the process. It contained about 13 tons of straw. The third pile (No. 3), of about the same amount of straw as No. 2, was given neither chemicals nor water. Its top was also levelled to make it open to the rainfall.

Temperatures were taken as a partial index of the activities in decomposition. These, together with the rainfall by periods, are recorded in Table 1. Pile No. 1, which received both reagent and water, indicated its decomposition by a prompt rise in temperature. Pile No. 2 failed to demonstrate much change until after five successive days of rain, August 16 to 29, inclusive, totalling 4.3 inches. Periodic fluctuations in temperature occurred with subsequent additions of rainfall. The temperature of Pile No. 3, without treatment, was scarcely ever higher than that of the atmosphere.

TABLE 1.—*Rainfall (inches) and temperature (°C) of artificial manure in farm trials in 1926.*

Pile number and straw treatment	Temperatures on dates recorded: August 1	August 8	August 15	August 20	August 22	August 30	September 5	September 14	September 23	September 28	October 2	October 15
No. 1 Chemicals and water added.........	44	45	54	51	70	53	38	59	59	10	32	50
No. 2 Chemicals only..	26	26	26	47	62	54	28	51	51	9	28	30
No. 3 No treatment...	26	25	26	24	37	38	20	38	38	7	18	22
Air temperatures	37	37	35	26	35	27	24	28	28	10	18	24
Rainfall between recorded dates	0.45	—	0.36	4.30[a]	—	0.85	5.92[b]	3.90	—	2.24[c]	2.31[d]	3.90

[a]Total for five successive days including date of record.

[b]Total for two successive days including date of record.

[c]Total for four successive days including date of record. Very low temperatures prevailed three days including date of record.

[d]Total for three of four days just preceding date of record.

Samples were taken at intervals and differences in decomposition noted. Both piles with chemical treatment showed highly discolored straw. This darkening of the color increased with time, while little evidence of decomposition was noticeable in the untreated straw. The pile given chemicals and water at the outset decayed in restricted but scattered areas where rainfall entered, showing that the initial application of water was insufficient. The pile receiving chemicals and the natural rainfall only decayed uniformly throughout. Fig. 1 illustrates the condition of this pile as compared with the pile given no chemicals. It was evident that the construction of the first pile prohibited uniform rain entrance and that the initial moistening was insufficient to continue the process. The second pile showed clearly that the rainfall could be used for the process, while the absence of decay in the check pile emphasized the importance of the chemicals.

DEGREE OF DECOMPOSITION

Samples from the three piles, taken after 70 days, were tested for degree of decomposition by following the method of Jones(3).

According to this method, a 6% solution of hydrogen peroxide may be used to measure the degree of decomposition, since it oxidizes partially decayed straw but does not attack the fresh material. The portion of the organic or combustible matter which was destroyed on treatment with hydrogen peroxide is shown by the data given in Table 2.

TABLE 2.—*Degree of decomposition of artificial manure after 70 days.*

Pile number and straw treatment		Appearance of sample	Percentage of combustible matter removed by H_2O_2	
No. 1	Chemicals and water added	Bright strawy	11.8	
		Slightly decayed	25.5	27.5
		Very well decayed	45.3	
No. 2	Chemicals only	Well decayed		37.5
No. 3	No treatment	Bright strawy		14.3

Pile No. 1, which received both water and chemicals, was so irregular in decomposition that three samples were used. The other two piles were uniform enough so that one single sample was deemed representative. It is interesting to learn from these data that the degree of decomposition was about two and a half times as great in pile No. 2 and twice as great in No. 1, both receiving the reagent, as in No. 3 with no treatment. In the very well decayed sample of pile No. 1 the decomposition was over three times that in the check, according to this method of measurement.

The data by the Jones method agreed in all respects with general appearances. To even the casual observer the resemblance to ordinary manure and the ease with which the material could be broken up agreed with the data for the test. By early December, or about 100 days after the start of the process, the straw given chemicals only was rotted well enough to be used as manure. That given both chemicals and water had rotted in limited areas, while the untreated straw showed little or no signs of decay.

In this connection it is well to remember that the speed of the process was due, in no small way, to the excessive rainfall during the trial, as shown in Table 1. During this period of the trial the total rainfall was more than double the normal. This raised the question whether in normal seasons the rainfall would deliver enough water for the process.

TRIALS OF 1927

To answer the above question more fully, the experiment was repeated in 1927. Three piles received the reagent applied through the thresher, while in the case of a fourth pile the reagent was applied by hand. The straw was put into flat piles about 6 feet high which

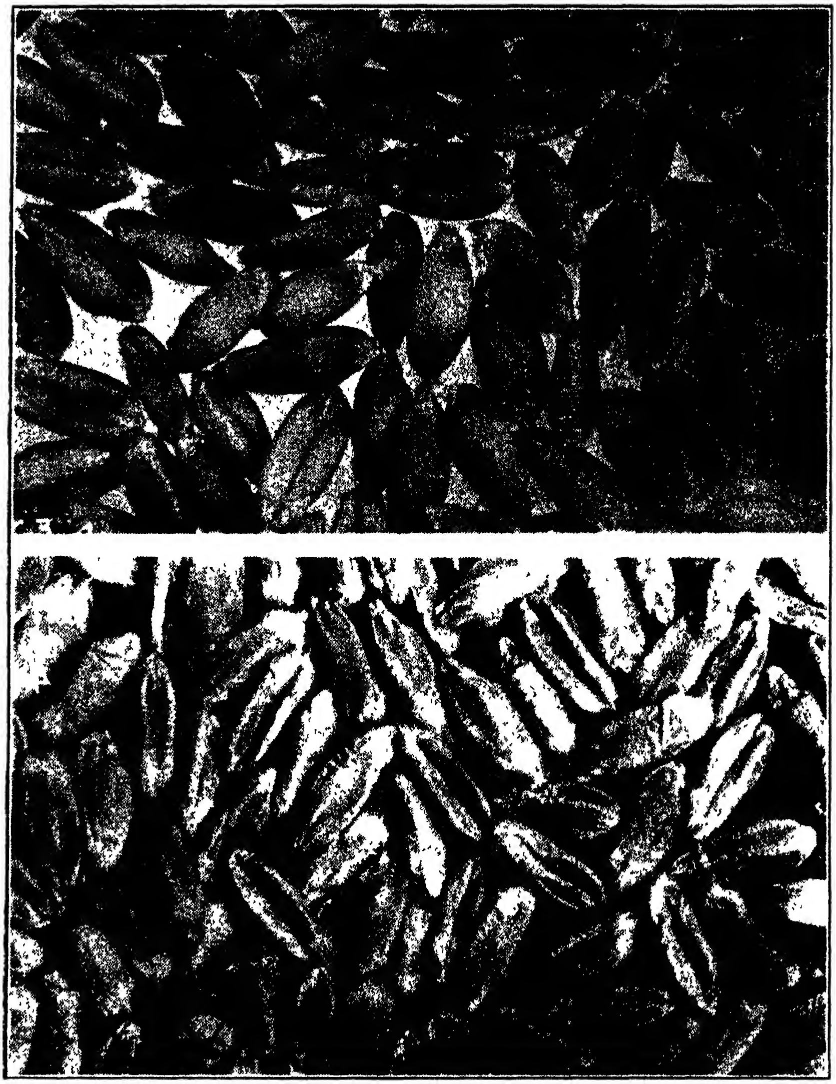

FIG. 2.—Quality differences in wheat resulting from the use of artificial manure. Above, Lime, superphosphate (acid phosphate), and artificial manure. Below, Lime and superphosphate (acid phosphate).

was estimated to be sufficient for normal rainfall. Dependence was placed entirely on the rainfall for moisture.

Unfortunately, the 1927 season, like that of 1926, suffered excessive rainfall, and the straw in piles 6 feet deep was converted to manure by October, earlier by two months than in the first trial when the piles were as high as 14 feet. The degree of decomposition in the

second trial after 60 days, as determined by the hydrogen peroxide test, was even greater than that shown in the first trial after 100 days. The material had all the appearances of and handled like manure and could have been used as a dressing for wheat land at seeding

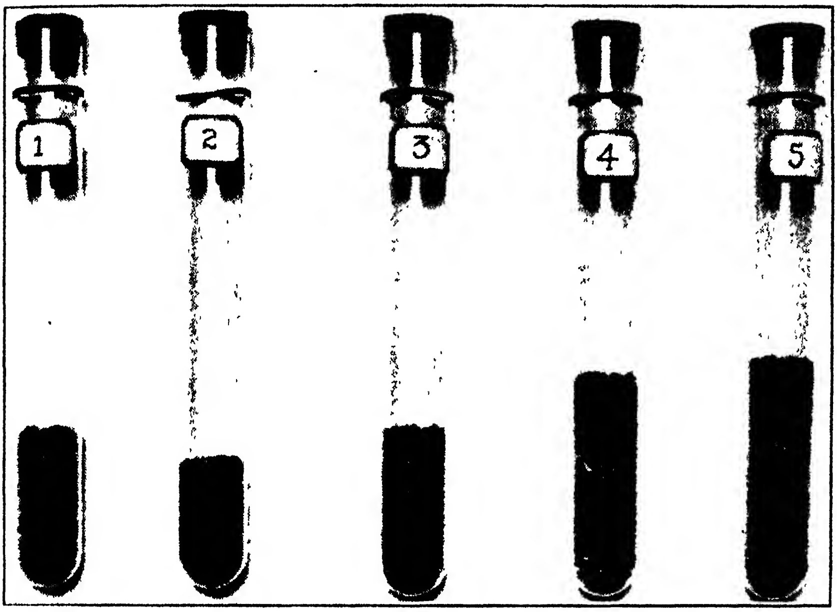

FIG. 3.—Yield differences in wheat resulting from the use of artificial manure. Left to right, Lime, and superphosphate (acid phosphate); lime, superphosphate (acid phosphate), and straw; lime, superphosphate (acid phosphate), and artificial manure (April); lime, superphosphate (acid phosphate), and artificial manure (December); and lime, superphosphate (acid phosphate), and artificial manure (December).

time. The pile given the reagent by hand was not as rapid nor as uniform in its decomposition and contained areas where little decay had taken place. This suggests the superiority of the method of applying the reagent through the thresher over its application by hand. Although both the 1926 and 1927 trials experienced high rainfall, the rapidity of the results suggests the possibility of varying the depth of straw to suit the normal rainfall and complete the process in a very short time.

FIELD TRIALS WITH ARTIFICIAL MANURE

If artificial manure making is to be fitted into the wheat farming scheme, for example, it should convert the straw of one crop into manure in time to serve as a winter top dressing for the next crop.

Such expectations of the process are not unfair according to the results of either year of these trials. In December 1926, the rotted materials and the unrotted straw from the three treatments were spread at the rate of six loads per acre on separate parts of a field of winter wheat whose uniformity would permit such a test. Barn-

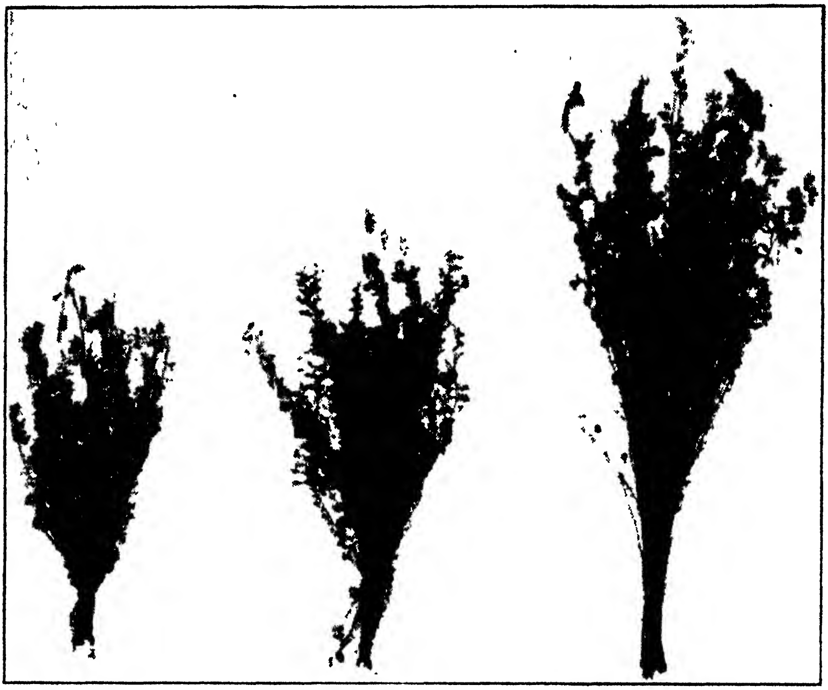

FIG. 4.—Sweet clover from stubble crop as produced (left to right) by lime and superphosphate (acid phosphate); lime, superphosphate (acid phosphate), and barnyard manure; lime, superphosphate (acid phosphate), and artificial manure.

yard manure was used for comparison. The soil was Cherokee silt loam. This is a soil of level topography with a dark gray silt loam surface of 8 to 10 inches and a distinctly tight or impervious subsoil. The land had been limed with 2½ tons limestone per acre in July previous to the wheat seeding in October. Two hundred pounds of 20% superphosphate (acid phosphate) went on the land with the wheat. A clover mixture was seeded about the middle of March.

Observations on the growing wheat revealed no marked differences, but differences in the clover were noticeable about the time wheat was maturing. Acre yields on the wheat were not taken, but 40 heads gathered at random gave differences in both yield and quality, the latter being the more noticeable (Figs. 2 and 3). Im-

provements in quality resulted regardless of whether the manure was applied in December or February and some effect was evident even when used as late as April. The dry straw from the untreated stack gave no improvement in the wheat.

The differences in the clover intensified themselves after the wheat harvest. Fig. 4 shows these for sweet clover harvested in late July. Alsike clover gave corresponding differences in size of the plants.

It is interesting to note the effects of the artificial manure above those by lime and phosphate on this soil type. It gave results superior to those of straw and it is especially noteworthy that its effects on sweet clover were greater than those of barnyard manure. Manure spelled the difference in this trial between a stand of clover and no stand. It suggests that the influence of the artificial manure was not one of mere cover, since straw giving this effect failed to guarantee clover, but that probably its influence was one of available nitrogen combined with phosphates, since the latter, even in conjunction with lime, failed to give a stand of the legume comparable to that obtained when these treatments were supplemented by the artificial manure. This empahsizes the importance of the possibilities of using such manure on certain soil types on which wheat farming is common.

The spring of 1927, when the effects on the clover were observed, was one of excessive rains and low temperatures. It is well to remember that under such conditions both the supply of nitrates and the process of nitrification would be low and the effects of available nitrogen might be intensified. This does not deny, however, the beneficial effects of the artificial manure in this trial.

DISCUSSION AND SUMMARY

Trials of artificial manure making under farm conditions suggest that this process may find a place in our more common farming schemes. The reagent should be applied at the rate of 150 pounds per ton of straw and should consist of 45% ammonium sulfate, 40% limestone, and 15% superphosphate (acid phosphate). Applying the necessary reagent through the thresher and putting the straw into flat piles of shallow depths make it possible to depend on the rainfall for moisture and to convert the straw into manure in ample time to be used with the least possible loss in bulk. This practice should encourage the utilization of common farm wastes to increase soil organic matter and to conserve soil fertility with no great expense.

With the recent decrease in price of commercial nitrogen, which

is the main item of cost in artificial manure making, and in the light of prospectively lower prices, the process may well be encouraged as a means of applying both more nitrogen and more organic matter to the soil with profit. The trials of two years suggest that artificial manure making may well receive consideration as an addition to the list of better farm practices.

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SEEDLING VIGOR AND DIASTATIC ACTIVITY OF DENT CORN AS RELATED TO COMPOSITION OF ENDOSPERM AND STAGE OF MATURITY[1]

Wendell R. Tascher and George H. Dungan[2]

INTRODUCTION

Experimental work in the field and laboratory has indicated that corn having a relatively corneous endopserm produces seedlings superior in vigor to those produced by grain soft or floury in composition. Both physical and chemical explanations have been given for this phenomenon. Dungan (5)[3] has reported that the starch reserves of horny corn disappear more rapidly during germination than those of floury corn. It is the purpose of this paper to present additional evidence of the relationship that exists between kernel composition and seedling vigor and to show that this relationship may be partially explained on the basis of the activity of hydrolytic enzyms in the germinating grain.

MATERIALS AND METHODS

The grain used was open-pollinated Reid yellow dent corn. All ears germinated well and were nearly disease free. Ears were harvested in each of four stages of maturity, namely, milk, glaze, dent, and mature There were 82 ears in the lot representing the milk stage, 81 the glaze, 97 the dent, and 43 the mature. The ears of each lot were classified into groups according to the relative amount of soft starch contained in the endosperm, following the method of Trost (8).

The temperature of the germinator was thermostatically controlled at 80° F. Each determination of sprout value was based upon not less than 40 seedlings. The plumules, radicles, and seminal roots were removed from the grain soon after the seedlings were taken from the germinator. These were dried to a water-free condition and weighed. All calculations were made on a water-free basis.

The seedlings used in the determination of diastatic activity were dried at 50° C and finely ground. Using an adaptation of the method of Pickler (6), 2 grams of this material were placed in a beaker with 25 cc of distilled water and allowed to digest an hour with agitation

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Peceived for publication November 12, 1927.

[2]Assistant in Crop Production and Assistant Chief in Crop Production, respectively.

[3]Reference by number is to "Literature Cited," p. 141.

by shaking every 10 minutes. The supernatant liquid was then drawn off and centrifuged 5 minutes. Five cc of the clarified liquid were placed in a flask and the reducing sugars were determined immediately. An equal aliquot was placed in a beaker with 20 cc of a 0.2% solution of Lintner's starch. This was placed in an electric oven at a temperature of 50° C and allowed to remain for three hours. The reducing sugars were then determined, using the Shaffer-Hartman (7) method.

MATURITY AFFECTS RAPIDITY OF GERMINATION

In some earlier work one of the authors (4) found that corn harvested in an immature condition absorbed water more rapidly and began the processes of germination more quickly than mature corn of the same variety. It was not until the end of the fourth day that the seedling development of the mature grains surpassed that of the less mature corn.

During the present studies, counts of the emerging plumules and radicles were made on a large number of kernels representing the different stages of maturity. Table 1 contains the data taken at the end of a 48-hour period on the germinator.

TABLE 1.—*Water absorbed and radicles and plumules produced during 48 hours at 80°F by lots of corn harvested at four stages of maturity.*

Stage of maturity	Number of kernels	Water absorbed %	Radicles emerged %	Plumules emerged %
Milk	2,400	69.76	62.6	3.48
Glaze	2,100	66.86	62.5	7.00
Dent	1,200	58.18	53.1	7.90
Mature	1,000	50.18	46.9	9.80

Even at the end of a two-day period of germination the mature corn had produced more plumules than the other lots. The percentage of radicles is in favor of the less mature corn which has the capacity of rapid water absorption. This situation suggests that the initial growth of the radicle is largely due to cell elongation—a process brought about by the intake of water—and that the extension of the plumule is accompanied by more complex metabolic changes within the kernel.

MATURITY INCREASES VIGOR OF CORN SEEDLINGS

A determination of the ratio of sprout to endosperm was made on these four lots of corn after a seven-day germination test. The results are presented in Table. 2.

TABLE 2.—*Weight of sprouts and endosperms of four lots of dent corn at the end of a seven-day germination test at 80° F.*

Stage of maturity	Number of seedlings	Average water-free weight of Sprouts (roots and plumules)	Endo-sperms	Ratio of sprout weight to endosperm weight	Ratio of sprout weight to air-dry kernel weight	Ratio of endosperm weight to air-dry kernel weight
		Grams	Grams	%	%	%
Milk....	834	0.0354	0.0847	41.79	21.59	51.67
Glaze...	824	0.0419	0.1100	38.09	20.41	53.60
Dent....	794	0.0493	0.1692	29.13	17.65	60.60
Mature.	439	0.0526	0.2201	23.89	15.68	65.79

The sprout weight increased regularly with increasing maturity of seed. The amount of endosperm remaining was also progressively greater with each stage nearer maturity. Corn in the milk stage produced roots and shoots the weight of which was 41.79% of that of the unutilized endosperm, whereas the mature corn produced sprouts that were only 23.89% of the remaining endosperm.

In order to determine the relative efficiency of these lots of corn in the production of sprouts, the difference between the weights of the grain before germinating and the unutilized endosperm after germination was considered as the amount of the endosperm required to produce the sprout. By calculating the proportion that the sprout is of the utilized endosperm, a figure is obtained which may be taken as an efficiency index. Table 3 shows the results of such computations.

TABLE 3.—*Germinative efficiency of corn harvested at different stages of maturity expressed as the percentage of endosperm required to produce sprout.*

Stage of maturity	Average weight of endosperm required to produce sprout	Average sprout weight	Efficiency (utilized endosperm weight divided by sprout weight)
	Grams	Grams	%
Milk......	0.0792	0.0354	44.69
Glaze.....	0.0952	0.0419	44.01
Dent.......	0.1100	0.0493	44.81
Mature.....	0.1144	0.0526	45.97

The data show a slightly higher germinative efficiency for the mature corn. Whether differences as small as these are significant is doubtful, although Blackman (1) points out that "a small difference in 'efficiency indices' of two plants may lead to a large difference in final weights."

SEEDLING VIGOR CLOSELY RELATED TO KERNEL COMPOSITION

Floury corn absorbs water more rapidly and, therefore, it would be expected to begin the germinative process sooner than horny corn. The emergence of the radicle commonly occurs slightly earlier

TABLE 4.—*Percentage of unutilized endosperm and sprout produced by floury and horny corn at different periods in the germinative process.*

Period of germination	Unutilized endosperm of		Sprout produced by	
	Floury corn	Horny corn	Floury corn	Horny corn
Days	%	%	%	%
2	98.34	98.01	0.02	0.03
2½	98.05	96.68	1.50	2.07
3	97.04	95.36	1.96	3.00
3½	93.76	92.70	3.94	4.68
4	89.39	87.83	6.35	7.62
5	75.94	73.86	15.10	16.55
7	59.03	57.17	23.52	25.36
9	45.25	39.90	31.20	34.98

in floury than in horny corn, but even so, the vigor of seedlings from horny seed surpassed that of seedlings from floury seed at the end of a two-day germination period as may be seen in Table 4. The data presented in Table 4 show the quantity of sprout and that portion of the grain not sprout, considered here as unutilized endosperm, expressed in terms of percentage of the original weight of the seed. These determinations were made on seedlings at intervals during germination.

TABLE 5.—*Water-free weight of sprouts produced by dent corn containing different proportions of soft starch and harvested at different stages of maturity.*

Composition	Average weight of sprouts produced by grains of corn harvested in the stage indicated				General average
	Milk	Glaze	Dent	Mature	
	Grams	*Grams*	*Grams*	*Grams*	*Grams*
Three-fourths floury.	10.86	——	——	——	10.86
One-half floury . . .	10.65	12.85	——	——	11.75
One-fourth floury	11.23	14.56	17.48	——	14.42
Horny	11.09	14.24	17.92	19.97	15.81
Very horny. . . .	——	14.60	19.10	22.29	18.66
Average . . .	10.96	14.06	18.17	21.13	16.08

The superiority in sprout value of the horny corn continued with increasing excellence throughout the period of the observations. At each period the percentage of unutilized endosperm was the greater in the floury corn. Fig. 1 shows graphically the relative rapidity of sprout development and endosperm utilization in the two lots of corn.

Further tests of the relation of kernel composition to seedling vigor were made, using the corn harvested at different stages of maturity. The ears of each lot were classified into groups according to the relative amount of soft starch contained in the endosperm of the grain. The data, which are the average sprout values for germination tests that ran 2-, 4-, 6-, 8-, 10-, and 14-day periods, are summarized in Table 5.

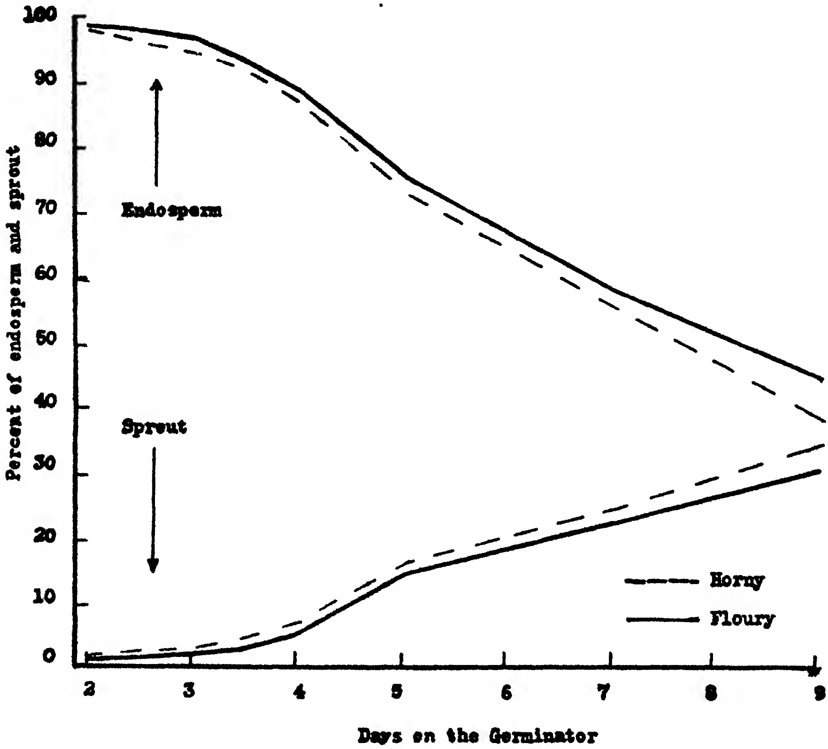

FIG. 1.—Percentage of unutilized endosperm and percentage of sprout produced by horny and floury corn at different periods in the germinative process.

The average sprout weight increased with the horniness of the grain. There was also a remarkably greater vigor of seedling as the grain matured. Much of this may be attributed to the kernels having a larger size in the mature corn. This explanation does not apply, however, to the corn possessing different amounts of soft starch. For instance, the horny and very horny lots of mature corn had approximately equal kernel weight, yet the sprout weight of the horny was 19.97 and of the very horny 22.29 grams.

In Table 6 the results at the end of four and eight days on the germinator are shown. It will be noted in this table that frequently

the endosperm weight of the horny group was less than that of the more floury lot; and yet in every instance of the two lots harvested at the same time, the average weight of sprout was greater for the more horny lot.

TABLE 6.—*Average weight of sprouts and unutilized endosperms of dent corn containing different proportins of soft starch and harvested at different stages of maturity.*

Stage of maturity	Days on germinator	Composition	Average weight of unutilized endosperms	Average weight of sprouts
			Grams	*Grams*
Milk	4	Three-fourths floury	5.18	0.58
		Horny	4.77	0.79
	8	Three-fourths floury	2.47	1.92
		Horny	2.14	2.18
Glaze	4	One-half floury	6.58	0.70
		Very horny	6.34	0.87
	8	One-half floury	3.11	2.56
		Very honry	2.42	2.69
Dent	4	One-fourth floury	8.93	0.75
		Very horny	9.27	0.84
	8	One-fourth floury	5.09	2.96
		Very horny	4.15	3.42
Mature	4	Horny	11.37	0.68
		Very horny	10.94	0.86
	8	Horny	6.43	3.48
		Very horny	5.96	3.56

A statistical analysis of the data presented in Table 6, using Student's method and pairing the two lots harvested at the same time, showed odds of 3,332 to 1, indicating that the horny character of the endosperm has a significant influence upon the size of seedling.

In this table, as well as in previous ones, the effect of time of harvesting upon sprout value is very apparent.

DIASTATIC ACTIVITY RELATED TO VIGOR

It has been thought that an explanation of the greater vigor of seedlings from horny as compared with that from floury corn lay in a difference in the activity of the starch-dissolving enzyms. Accordingly, tests of the activity of the diastatic extract from horny and

TABLE 7.—*Diastatic activity of floury and horny corn harvested at different stages of maturity expressed in terms of milligrams of glucose.*

Composition	Reducing sugar formed from 0.04 grams of starch by extract from corn harvested in the stage indicated				Average
	Milk	Glaze	Dent	Mature	
	Mgs.	*Mgs.*	*Mgs.*	*Mgs.*	*Mgs.*
Extremely floury....	3.00	2.75	1.33	1.50	2.15
Extremely horny....	2.95	2.62	1.32	2.57	2.37

floury corn were made by determining the ability of the extract to hydrolyze equal quantities of Lintner's starch. The ungerminated air-dry corn was used in the first test. The results appear in Table 7.

The average of all the determinations showed slightly higher diastatic activity in the extremely horny corn, but since the results are so nearly the same for both lots and since three of the four determinations showed a higher diastatic activity for floury corn, it is believed that this difference in the average in favor of horny corn cannot be considered significant. There seemed to be a tendency for the diastatic activity to decrease as the corn matured, although there was an upward swing in the lots harvested in the mature stage. These results are in harmony with those of Bradley and Kellersberger (2), who, working with corn harvested at different stages of maturity, obtained the following relative diastatic activity: Corn seeds young, 10.0; corn seeds medium, 6.7; and corn seeds mature, 7.7.

Waksman and Davison (9) reported that the small grains of barley produced more diastase than the large ones. The fact that the early harvested corn produced a more active enzym than the later harvested lots may be due to the fact that the kernels of the early harvested corn were smaller. Brown and Morris (3), however, reported that in barley the enzym activity increased with maturity, being approximately one-half as active when the endosperm was one-half developed as when mature.

DIASTATIC ACTIVITY OF GERMINATED CORN

Brown and Morris (3) obtained a relative diastatic activity of barley embryos at the end of three days on the germinator of 0.1186 and at the end of six days of 0.2432. The data in Table 8 harmonize with their conclusions, indicating that during the germinative process the diastatic activity of corn increases. The stage at which the seed corn was harvested did not influence the diastatic activity of the grain to any appreciable extent.

TABLE 8.—*Diastatic activity of corn at different periods in the germinative process.*

Period of germination	Reducing sugar formed from 0.04 grams of starch by extract from corn harvested in the stage indicated				Average
	Milk	Glaze	Dent	Mature	
Days	*Mgs.*	*Mgs.*	*Mgs.*	*Mgs.*	*Mgs.*
2	3.30	3.45	3.61	3.63	3.50
6	3.73	3.91	3.40	3.77	3.70
10	4.50	4.70	4.45	4.25	4.48
14	5.00	5.10	4.70	5.00	4.95
Average	4.13	4.29	4.04	4.16	4.16

It appears that differences found to occur in the vigor of corn seedlings produced by seed harvested at different stages of maturity

cannot be explained by differences in activity of diastase. The superior vigor of seedlings from mature corn may be due primarily to the greater quantity of reserves which the longer period on the parent plant made possible.

When the horny and floury lots of corn were compared in a test of diastatic activity, some interesting results were obtained. The data secured are summarized in Table 9.

TABLE 9.—*Diastatic activity of germinated corn containing different proportions of soft starch.*

(An average of determinations made after 2, 6, 10, and 14 days on the germinator.)

Composition	Reducing sugar formed from 0.04 gram of starch by extract from corn harvested in the stage indicated				Average
	Milk	Glaze	Dent	Mature	
	Mgs.	*Mgs.*	*Mgs.*	*Mgs.*	*Mgs.*
Extremely floury. . .	3.95	4.31	3.90	4.05	4.05
Extremely horny. .	4.35	4.20	4.15	4.21	4.23
Average.	4.15	4.26	4.03	4.13	4.14

The sugar formed by the extract from seedlings produced by the horny corn was 4.23 as compared to 4.05 for the floury corn. Using Student's method for figuring odds and comparing the results obtained at the end of the two-and six-day periods on the germinator, the odds are 434 to 1 against the greater diastatic activity of the horny corn being due to chance. When the results after 10 and 14 days are compared, the odds are 36 to 1.

With a more active diastase in horny than in floury corn, one might expect to find a greater accumulation of sugar in horny than in the floury grain. The data contained in Table 10 show the milligrams of reducing sugar expressed as glucose in the two lots of corn.

TABLE 10.—*Reducing sugar content of germinated corn containing different proportions of soft starch.*

(An average of determinations made after 2, 6, 10, and 14 days on the germinator.)

Composition	Reducing sugar in corn seedlings the seed of which had been harvested in the stage indicated				Average
	Milk	Glaze	Dent	Mature	
	Mgs.	*Mgs.*	*Mgs.*	*Mgs.*	*Mgs.*
Extremely floury. . .	6.80	6.20	6.40	6.60	6.50
Extremely horny. . .	5.90	5.65	6.35	5.80	5.93
Average.	6.35	5.93	6.38	6.20	6.22

There was in every case less sugar in the seedlings from horny than from floury corn, despite the fact that the starch hydrolytic enzym was more active in the former. This situation would indicate that the sugars formed are utilized more rapidly by the vigorous seedlings produced by the horny seed.

SUMMARY

In a study of the influence that the composition of the endosperm and stage of maturity of seed corn have on the diastatic activity and vigor of seedlings during germination the following phenomena were revealed.

1. During the germinative process, radicles emerged more rapidly and plumules less rapidly in early harvested corn than in mature seed.

2. Corn harvested in the mature stage produced heavier sprouts than that harvested in the milk, glaze, or dent stages.

3. Horny corn produced sprouts that were 0.148 gram heavier, as an average, than those from floury corn with odds of 3,332 to 1 that this difference was significant.

4. Tests made during the germination of corn showed a relative diastatic activity of 4.23 for horny corn and 4.05 for floury corn with odds sufficiently high to indicate significance.

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SOME TYPES OF VEGETATION IN RELATION TO THE SOIL PROFILE IN NORTHERN COLORADO[1]

HERBERT C. HANSON AND FREDERICK B. SMITH[2]

INTRODUCTION

Along the eastern front of the Rocky Mountains the vegetation varies considerably. Short grasses characteristic of the plains, tall grasses of the prairies, shrubs of the exposed foothill slopes or ravines, and mountain conifers occur within a short distance. A number of papers (2, 7, 8, 9, 10, 11, 15, 16)[3] have been published which describe and map this diversified vegetation, especially in the vicinity of Boulder, Colorado. Adjacent areas frequently differ sharply in their vegetative cover. Often close grazing is an important factor in causing these differences in cover as where short grasses replace the taller wheat grass. It has been shown by Marbut (5), however, and by Shantz (13) that on the Great Plains soil conditions are highly important factors in causing such differences.

Shantz has correlated the types of vegetation on the Great Plains to the more important environmental factors. He points out that the short grasses are dominant when the carbonate layer is from 8 to 18 inches below the surface. Porcupine grass (a tall grass) dominates with grama grass (a short grass) when the carbonate layer is 15 to 24 inches deep. Western wheat grass is best developed in the Pierre clays of South Dakota in which moisture penetrates slowly and the carbonate layer is 14 to 24 inches deep.

This study was undertaken to investigate the relationship between certain types of native vegetation and the soil profiles in northern Colorado. The most effective management of range lands is in a large measure dependent upon soil conditions. The texture, consistence, moisture content, and depth of the carbonate layer often determine the endurance of various types of grassland to close grazing. The carrying capacity, the effects of overgrazing, the best methods of restoring a depleted range, and many similar problems are closely related to soil conditions.

DESCRIPTION OF REGION

The region covered in this report lies along the eastern foothills of northern Colorado adjacent to Fort Collins. The plains, except

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[3]Reference by number is to "Literature Cited," p. 150.

as they are broken by stream valleys, extend up to the base of the foothills. Mesas, usually present in the Boulder region, are not developed here. Fig. 1 presents graphically the geology of the area (3, 4).

These soils have developed recently and the profiles are immature. Profiles 1, 2, and 3 are closely related to the geological formations from which they are derived, while others, as profile 6, bear little or

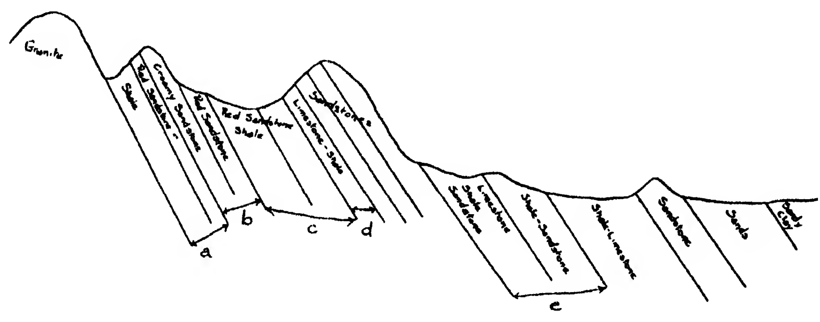

Fig 1 Geology foothills area northeastern Colorado

no relation to the formation underlying them. Profile 6 (Fig. 4) is representative of much of the uplands adjacent to the larger streams and is derived from material laid down and worked over by these streams when they were much larger than they are now. The A horizons have attained a fair degree of development and in some instances a well developed B horizon is evident, varying with local conditions.

The foothills section consists of from two to five north and south ridges formed by the more resistant sandstones and sandy limestones with intervening narrow to broad valleys derived from the soft red sandstones and shales. Mountain streams have cut through these ridges at right angles, forming canyons, depositing sand and gravel, and modifying the adjacent level areas.

CLIMATE

The climate in this region is characterized by fairly low precipitation, low humidity, high evaporation, high percentage of possible sunshine, rather frequent long dry spells, and considerable variability due to the nearness of the foothills and mountains.

The mean annual precipitation for a period of over 42 years at Fort Collins (elevation 4,985 feet) is 14.77 inches. During 1893, the precipitation was only 5.65 inches, during 1915 it was 22.79 inches.

Most of this comes during the spring and early summer. The distribution throughout the year is as follows: January, 0.44 inch; February 0.61; March, 0.93; April, 2.13; May, 2.84; June, 1.49; July, 1.83; August, 1.22; September, 1.28; October, 1.07; November, 0.47; and December, 0.46. Since most of the surface slopes, often considerably, the run-off is high.

Much moisture is also lost through evaporation. The average annual evaporation for 31 years at Fort Collins is 40.59 inches. This was measured by the use of a tank 3 x 3 feet about 2 inches above the soil surface. The yearly distribution is as follows: January, 1.23 inches; February, 1.45; March, 2.63; April, 4.21; May, 4.68; June, 5.42; July, 5.59; August, 5.07; September, 4.30; October, 3.28; November, 1.56; and December, 1.17. The high evaporation rate is caused by rather low humidity, wind velocity that averages annually 15 miles per day, and a high percentage of possible sunshine, averaging about 65% for the year.

The season free from killing frosts, averaging the record of 28 years, extends from May 8 to September 27, a total of 138 days. The latest spring frost has come as late as June 3 and the earliest on September 7. The mean annual temperature at Fort Collins is 46.4°F. July and August are the warmest with means of 68.0°F and 67.5°F, respectively. January, with a mean of 26.2°F, is the coldest.

PROFILES

PROFILE NO. 1

This profile has developed on level to gently sloping areas cut at right angles by the mountain streams, canyons, and dry creeks. The soil material represents deposits of sediment laid down by these streams. The material was gathered by the streams as they traveled over granitic rocks, the soft red sandstones and shales, and the light-colored limey sandstones which form the first ridge. The profile of a virgin soil of this area is shown in Fig. 2. Many roots occur in the A_0 and A_1 horizons and as the roots decay they give to the soil a dark brown to black color.

Horizon A_0, 0-2 inches, black loam, granular,

Horizon A_1, 2–36 inches, uniform dark brown loam, massive.

Horizon B, 36-42 inches, mottled gravelly loam, zone of high salt concentration, cemented.

Horizon C, 42 inches, sandstone gravel, parent material.

The vegetation on soils represented by this profile consists chiefly of western wheat grass (*Agropyron Smithii* Rydb.), sleepy grass (*Stipa Vaseyi* Scribn), and grama grass (*Bouteloua gracilis* Lag.).

Other common plants were beard-tongue (*Pentstemon unilateralis* Rydb.), sunflower (*Helianthus annuus* L.), white sweet clover (*Meliotus alba* Desv.), and rabbit-brush (*Chrysothamnus graveolens* (Nutt.) Greene). Most of these plants are deep-rooted, requiring a soil that contains moisture to a depth of 6 to 9 feet. Sleepy-grass and beard-tongue especially are deep-rooted, penetrating to 9 to 11 feet. The presence of grama grass is due mostly to overgrazing.

FIG. 2.—Profile 1, found in a valley between two foothill ridges. The principal plants are western wheat grass, sleepy grass, and grama grass.

The soil profile (Figs. 1 and 2) shows well developed loam to a depth of about 3 feet, providing a very favorable medium for the root development of these plants. The zone of salt concentration varies in thickness and density and is not compact enough to hinder root growth. Much run-off is received on this soil from adjacent slopes. Very good dry-land wheat is grown here.

PROFILE NO. 2

The weathering *in situ* of the soft red sandstone and shales (Fig. 1, b and c) has produced two similar profiles except for texture and zone of salt concentration. These rocks have weathered into deep, uniform red soils in the broad level valley between the first two ridges or foothills.

Horizon A_0, 0–2 inches dark red loam, granular.

Horizon A_1, 2-30 inches, uniform dark reddish-brown clay loam, compact.

Horizon B, 30-36 inches mottled sandy clay, zone of high salt concentration, weakly cemented.

Horizon C, 36 inches- , shale, sandstone.

This deep, fine-textured soil makes possible a splendid stand of a mixture of deep-rooted grasses with interspersed shrubs or half-shrubs. Western wheat grass and grama grass were very thrifty, the former 2 feet tall. Other common grasses were sleepy-grass, porcupine grass (*Stipa comata* Trin. & Rupr.) 2 to 3 feet tall, drop-seed (*Sporobolus cryptandrus* (Torr.) Gray) 3 feet tall, mountain-rice (*Eriocoma cuspidata* Nutt.), and wild rye (*Elymus canadensis* L.). Half-shrubs occurring rather frequently were mountain sage (*Artemisia frigida* Willd.), winter fat (*Eurotia lanata* (Pursh.) Moq.), and wild buckwheat (*Eriogonum effusum* Nutt.). Snowberry (*Symoricarpos occidentalis* Hook.) was found rarely. Most of these species and their good growth indicated a soil that provided for deep root growth as well as plenty of soil moisture throughout the growing season.

PROFILE NO. 3

This profile has developed on the shaly sandstone and is very similar to No. 1, except that no zone of high salt concentration is found. This profile is not developed extensively, but where it occurs it furnishes some of the most productive non-irrigated farms in the foothills section. Roots occur throughout the profile. The soil is retentive of moisture and the deeper rooted grasses do well.

Horizon A_1, 0-4 inches dark red friable sandy clay.

Horizon A_2, 4-36 inches, red loam, compact.

Horizon A_3, 36-72 inches, yellow fine sand.

A dense stand of western wheat grass, very leafy and fruiting heavily, was produced on this soil. The stand was pure except for occasional plants of sleepy-grass and *Astragulus* spp. Better growth of wheat grass is not found in this section so this soil may be considered highly favorable for wheat grass.

PROFILE NO. 4

This soil is limited to the lower part of the steep western slope of the second ridge in the foothills section where the silicious limestones are typically developed. Horizons A_0 and A_1 are well supplied with fibrous roots, and some roots occur in the A_2 horizon, although 10 inches is usually the limit of moisture penetration. This accounts for the difference in color of the two horizons.

Horizon A_0, 0–2 inches black loam, friable.

Horizon A_1, 2–8 inches dark brown, loam, roughly cubical.

Horizon A_2, 8–24 inches, light brown loam, roughly cubical.

Horizon B, 24–30 inches, gray, very fine sandy loam, zone of salt concentration, weakly cemented.

Horizon C, 30 inches–, limestone and shales.

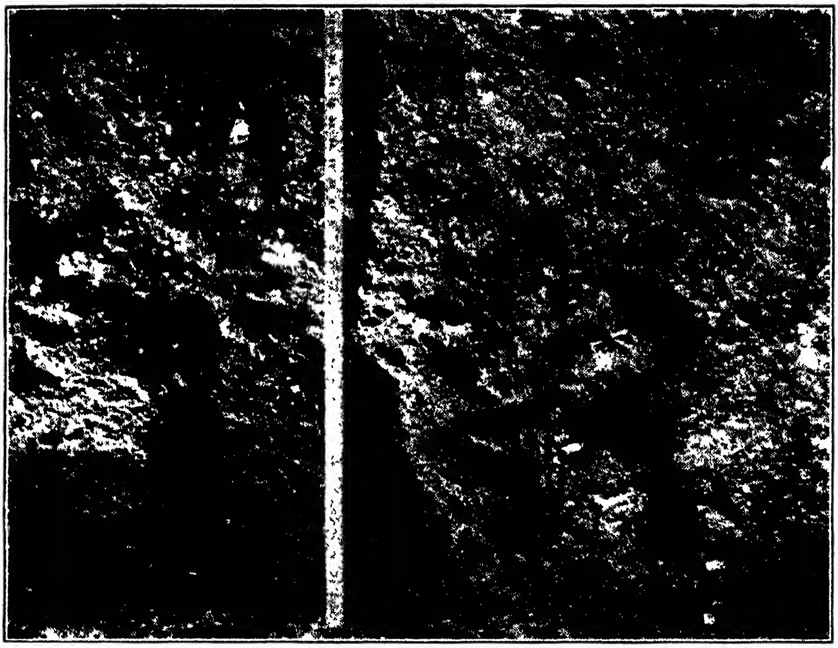

FIG. 3.—Profile 5. The vegetation was chiefly grama grass and ring muhlenbergia. The roots did not penetrate the cemented layer where the layer was well developed.

Western wheat grass was much sparser on this soil, due chiefly to more limited soil moisture and partly to overgrazing. High run-off was occasioned by the sloping surface. Most of the vegetative cover was grama grass. The roots of this grass are mostly in the upper 2 feet of the soil. Snakeweed and mountain sage were scattered. A few plants of low rabbit-brush and wild buckwheat also grew here. The carbonate layer was not sufficiently developed to hinder root growth.

PROFILE NO. 5

This profile occurs north of Fort Collins and is typically developed on a low north and south ridge (Fig. 1, e). The soil is derived from thin limestone, sandstone, and shale formations. The "so-called"

hardpan layer is well developed at from 8 to 14 inches deep. Moisture penetration is shallow and evaporation rapid. A detail of this profile is shown in Fig. 3.

Horizon A, 0–12 inches, sandy gravel.

Horizon B, 12–42 inches, gravel, cemented.

Horizon C, 42 inches – , sandstone, shale.

The vegetation on this soil was chiefly grama grass and ring muhlenbergia (*Muhlenbergia gracillima* Torr.). Both of these are

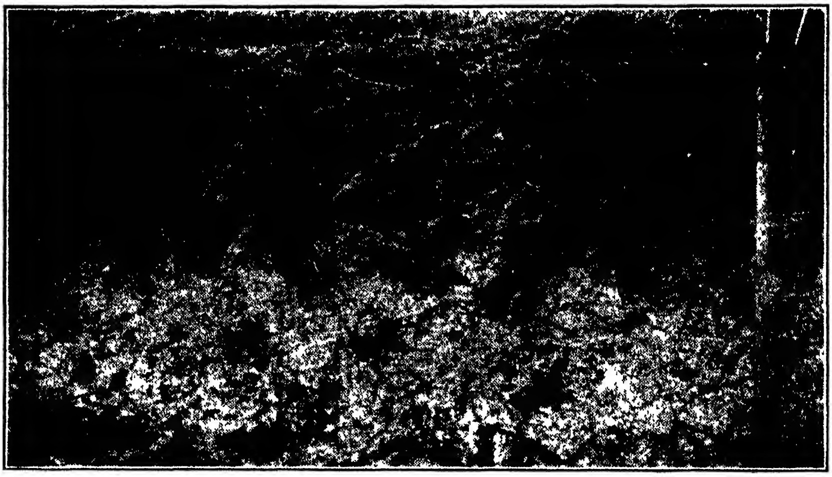

FIG. 4.—Profile 6, found on the bench-land along the Poudre River. Good stands of western wheat grass grow on this soil. Sugar beets, grain, and alfalfa are produced under irrigation.

short grasses characteristic of the Plains. The roots occur chiefly in the upper foot or two of soil. Snakeweed was scattered. In many places the hardpan-like layer was so well developed as to prevent root growth through it. The roots usually spread out horizontally until a less compacted section was reached where the roots grew downward again. (See Fig. 3.) Where the cemented layer was less well developed the roots grew more directly downward, and the degree of this development was indicated by the vegetation. When this layer was well developed and only 6 to 8 inches below the surface, the vegetation was more open, there was less grama grass, and much ring muhlenbergia. When the layer was poorly developed or about 14 inches or more deep, then the vegetation was more dense, there was more grama grass, and very little or no muhlenbergia. This profile, in connection with surface diggings, showed that the depth and hardness of the carbonate layer are indicated by the kind and density of the vegetation.

PROFILE NO. 6

This profile illustrates the development of soils in the irrigated sections of this region which occur on the bench lands along the larger streams. The soil material is outwash from the hills that has been worked over by stream action and has attained a fair degree of development in the upper horizons. Roots are well distributed throughout horizons A_1, A_2, and B.

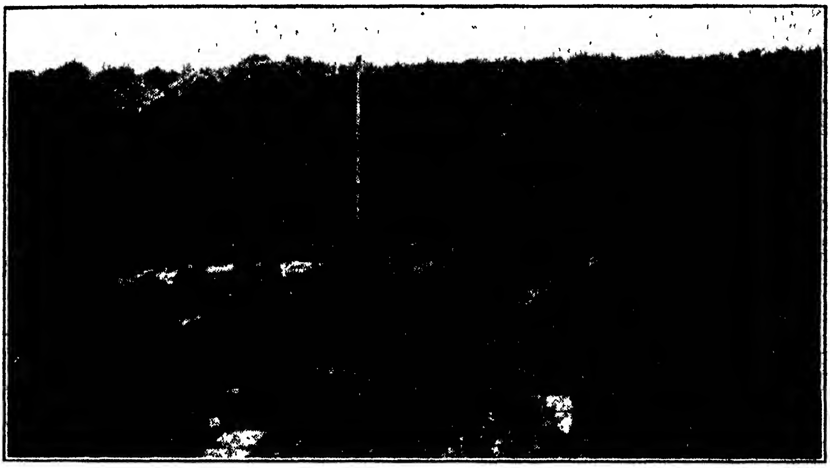

FIG. 5.—Profile 7, characteristic of the plains area east of Wellington. Vegetative cover is chiefly grama grass and sedge.

Horizon A_1, 0-4 inches dark brown sandy loam, granular.

Horizon A_2, 4–16 inches, brown fine sandy loam, coarse granular.

Horizon B, 16-36 inches, mottled fine sandy loam, zone of high salt concentration, cloddy.

Horizon C, 36-72 inches, uniform yellow fine sand, shale.

This soil supports a good stand of western wheat grass when not overgrazed. Most of it is now under irrigation and grows excellent crops of sugar beets, grain, and alfalfa.

PROFILE NO. 7

Much of the plains area, or non-irrigated section of northern Colorado, is typically represented by this profile, (See Fig. 5.). The A_2 horizon varies in depth but is characteristically the same throughout its occurrence. The A_1 horizon is the limit of penetration of most of the roots. Moisture penetration is very shallow. Farther east the A_2 horizon is from 2 to 15 inches brown loam, columnar structure, and a well developed B horizon is found below 15 to 18 inches.

Horizon A_1, 0-8 inches, light brown sandy loam, hard.

Horizon A_2, 8-36 inches, brown sandy loam, roughly cubical.

Horizon C, 36-40 inches, argillaceous sandstone, limestone.

Typical short grass plains vegetation was growing here. The most abundant species was grama grass. A low sedge (*Carex stenophylla* Wahl.) was also abundant. Both of these plants, with their shallow root systems and capacity to endure drought, are well adapted to this soil and climate. Other common plants growing here were snakeweed, false mallow (*Malvastrum coccineum* (Pursh.) A. Gray), gumweed (*Grindelia squarrosa* (Pursh.) Duval), and soapweed (*Yucca glauca* Nutt.). This area was somewhat overgrazed

CONCLUSIONS

A large variety of soils occur in the Fort Collins region. These vary from a variety of alluvial deposits, residual sandstones, shales, and limestones to wind blown material.

The tall grasses such as porcupine grass, sleepy grass, wild rye, as well as western wheat grass, grow well on deep loam and clay soils, often containing considerable sand or gravel, provided the moisture penetrates sufficiently deep for the growth of the roots. Such conditions occur in the valleys between the foothills and on the plains immediately adjacent to the foothills.

The short grasses, grama grass, buffalo grass, and ring muhlenbergia, are dominant on compact soils that contain available moisture during part of the growing season in only the surface 6 to 24 inches. This kind of soil is found on the plains a few miles east of the foothills. Taller grasses do not occur except in depressions where western wheat grass and porcupine grass may be found.

The so-called hardpan layer was found to impede or prevent downward growth of roots on the plains in places. The depth and hardness of the cemented layer was indicated by the character and density of the vegetation. A thin stand of grama grass and ring muhlenbergia indicated shallow well-developed hardpan-like structure. Denser stands of grama with little or no muhlenbergia indicated a deeper and often more weakly cemented layer.

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IMMUNITY OF HOPE WHEAT FROM BLACK STEM RUST INHERITED AS A DOMINANT CHARACTER[1]

J. ALLEN CLARK and E. R. AUSEMUS[2]

Hope is a new variety of hard red spring wheat which so far has been practically immune in the field from attack by black stem rust, and also immune from or highly resistant to certain other wheat diseases, including leaf rust and bunt or stinking smut. This combined immunity from or resistance to these several diseases, and especially the immunity from stem rust, is of great importance at this time from a plant-breeding standpoint.

ORIGIN AND CHARACTERS

Hope was bred and selected from a cross of Marquis wheat on Yaroslav emmer by E. S. McFadden of Day County, South Dakota. It was first distributed commercially by Mr. McFadden in the spring of 1927. Hope is a true common wheat with bearded spikes (Fig. 1), white glabrous glumes, and midsized hard red kernels. From limited experiments and the experience of growers it appears to be a fairly high-yielding variety under unfavorable rust or drought conditions, but does not have the capacity for large yields under favorable conditions. Because of the value and limited amount of Hope seed, comparable milling and baking tests of this with other varieties have not been made. Crude protein tests from nursery experiments at several agricultural experiment stations indicate that it has a good quantity of gluten. Many additional data are needed to determine if Hope wheat possesses sufficient merit to make it a successful commercial variety. The more important fact at this time, however, is that the immunity of Hope wheat from black stem rust and other diseases can be transmitted readily to selections from its crosses with other varieties.

The development of a common wheat with the immunity of emmer has greatly simplified the problems of breeding, because crosses with Hope wheat are made with greater ease than crosses with emmer and little or no sterility is encountered, as is usually the case with species crosses.

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FIG. 1.—Spike and kernels of Hope wheat.

RUST REACTION

Varieties of wheat may be separated genetically as to rust reaction into three groups, *viz.*, (a) susceptible, (b) resistant, and (c) immune. Most varieties of wheat are susceptible to black stem rust. For many years certain durum varieties have been recognized as resistant to the disease. In recent years several resistant hard red spring varieties have been discovered or bred. Until the production of Hope wheat, only certain varieties of emmer could be classed as practically immune. In each of these groups there is variability and overlapping due to seasonal conditions and plant development, as well as to the prevalence of the disease and the physiologic forms of stem rust present.

SUSCEPTIBILITY

The more important varieties of hard red spring wheat rank in descending order of their susceptibility to black stem rust under field conditions in the spring wheat states as follows: Red Bobs, Supreme, Preston, Haynes Bluestem, Power, Marquis, Reliance, and Ruby. Susceptibility in any of these may vary from 100 down to 20% of infection, according to conditions. The susceptible durum varieties usually carry less rust than the susceptible common varieties, varying from 75 to 10%, and may be ranked as follows: Kahla, Peliss, Arnautka, Mindum, Mondak, and Kubanka.

RESISTANCE

The varieties of hard red spring wheat which possess resistance to black stem rust varying from 30 to 1% under rust conditions may be ranked in descending order of their average infection as follows: Progress, Ceres, Marquillo, Kota, and Webster. The resistant durum varieties having an average infection varying from 20 to 0% are Nodak, Acme, Monad, and Pentad.

IMMUNITY

Only the Hope variety of hard red spring wheat can be classed as practically immune. Its reaction is similar to that of the Khapli, Vernal, and Yaroslav varieties of emmer which usually are rust free but may carry a trace of from 1 to 2% under conditions of maximum infection. It is important to determine how the immunity of Hope wheat, obtained from emmer, is inherited in comparison with the resistance of certain hard red spring and durum varieties.

INHERITANCE OF RUST REACTION

The inheritance of rust resistance and immunity has been found to be rather complicated. This is due not only to the several genetic

factors which may be involved, but also to the existence of many physiologic forms of stem rust. Under field conditions, several forms of stem rust may be present and the rust reaction of hybrids has not been found to be inherited in any definite genetic ratio. In the rust nursery at University Farm, St. Paul, Minn., where nine physiologic forms of stem rust were used as inoculum for Kota x Marquis hybrids under field conditions, Hayes and Aamodt (6)[3] found that, "In one group of 206 F_3 families there were 28 which were as resistant as Kota. This is in a ratio of 1 to 7.36. In another test there was a ratio of 1 resistant F_3 family to 8.1 susceptible and heterozygous."

In crosses between Kota and Hard Federation under field conditions, Clark (4) found that, "Resistance to stem rust proved recessive and in F_2 appeared to occur close to a 1:15 ratio. In F_3, however, not one of nearly 300 resistant F_2 plants bred true for resistance... Evidence was shown that strains homozygous for resistance could be obtained in F_4."

In the cases of Ceres and selections of 1656 from the Kota-Marquis cross, Waldron (8) obtained resistances in the F_3 and later generations, respectively, nearly equal to and greater than, that possessed by the Kota parent.

Under controlled greenhouse conditions, Hayes and Aamodt (6) found, "Kota immune from Form XXVII, while Marquis proved resistant. Immunity appeared to be dominant to both resistance and susceptibility."

In a cross between Kanred and Marquis, Aamodt (1) also found in the greenhouse with Form 1, "A simple Mendelian ratio of approximately three immune plants to one susceptible plant."

Aamodt (2) later concluded that, "There is a multiple allelomorphic series of three factors which governs the reaction of Marquis, Kota, and Kanred to physiologic Form I."

It thus has been found with certain forms of stem rust under controlled greenhouse conditions that the immune reaction is dominant to either susceptibility or resistance, but that in the field resistance is recessive to susceptibility. The dominance of immunity and recessiveness of resistance also have been found with bunt or stinking smut of wheat by both Gaines (5) and Briggs (3). A similar reaction to leaf rust also has been found for wheat by Mains, Leighty, and Johnston (7).

The dominance of immunity of the Hope variety from black stem rust under field conditions is striking. On Mr. McFadden's farm in

[3]Reference by number is to "Literature Cited," p. 158.

Day County, S. Dak., in 1927, F_1 plants of a Hope-Supreme cross had but a trace of stem rust, and that located above the upper nodes of the stems, when Supreme was 100% infected and Hope was entirely rust free.

The writers obtained information on the dominant inheritance of immunity from stem rust in Hope hybrids from a series of crosses planned jointly and made at the Northern Great Plains Field Station, Mandan, N. Dak., in the summer of 1926. Some of the F_1 plants were grown in a greenhouse at the Arlington Experiment Farm, Rosslyn, Va., in the winter of 1926-27. Other F_1 plants and F_2 populations were grown at Mandan, N. Dak., in 1927. An abundance of natural stem rust infection in the nursery at Mandan made it possible to obtain data on the stem rust reaction of several crosses. All F_1 plants having Hope as one parent were rust free or had but a trace of infection. In addition to the F_2 studies from several crosses, discussed later, it also was found that strains homozygous for immunity from stem rust were obtained in the F_3 generation of a Hope-Reliance cross. This cross was made in a greenhouse at Arlington Farm in the winter of 1925-26. The F_1 plants were grown at Mandan in the summer of 1926. An F_2 population of the Hope-Reliance cross grown in the greenhouse at Arlington Farm, in 1926-27, was the source of seed of the F_3 strains grown at Mandan in the summer of 1927. Two generations of hybrids thus are grown each year through the use of greenhouse facilities.

The F_2 results may be discussed under three groupings, *viz.*, (a) resistant x susceptible, (b) immune x susceptible, and (c) resistant x immune. Results of a few crosses studied will be used to illustrate the type of stem rust reaction obtained under natural field conditions.

RESISTANT X SUSCEPTIBLE CROSSES

Three crosses, Nodak x Red Bobs, (Kota x Webster) x Red Bobs, and Marquillo x Red Bobs, may serve to show the reaction of this group of crosses to stem rust in the field. The Red Bobs parent used was a pure-line selection known as C. I. 6255-26, which is very susceptible to stem rust. The Kota x Webster parent is an unnamed hybrid selection which combines the resistance of the two parent varieties. Marquillo is of hybrid origin, obtaining its resistance from the Iumillo durum wheat. The Nodak x Red Bobs cross was a species or subspecies hybrid and much sterility was present. This accounts for the few F_2 hybrid plants obtained. The data for the three crosses are given in Table 1.

TABLE 1.—*Segregation of F_2 plants of Nodak x Red Bobs, (Kota x Webster) x Red Bobs, and Marquillo x Red Bobs crosses in comparison with parents into frequency classes for stem rust infection at Mandan, N. Dak., in 1927.*

Stem rust infection percentage	Numbers of plants by infection classes: Nodak x Red Bobs cross: Nodak	F_2 hybrids	Red Bobs	(Kota x Webster) x Red Bobs cross: Kota x Webster	F_2 hybrids	Red Bobs	Marquillo x Red Bobs cross: Marquillo	F_2 hybrids	Red Bobs
10	51			19			9	1	
20				9			17	1	
30							4	8	1
40					63			102	11
50		5	17		69	4		146	17
60		2	54		51	14		114	61
70		8	16		20	15		41	16
Total	51	15	87	28	203	33	30	413	106
Average	10	62	60	13	51	63	18	52	58

These data show that under field conditions at Mandan, N. Dak., in 1927, susceptibility, in resistant x susceptible crosses, was inherited as a dominant character.

IMMUNE X SUSCEPTIBLE CROSSES

Two crosses, Hope x Marquis and Hope x Reliance, serve to show the reaction of this group of crosses to stem rust in the field. Marquis is the principal commercial variety of hard red spring wheat and is one parent of both Hope and Reliance. Reliance is a selection from a Kanred x Marquis cross and in the greenhouse contains the immunity of Kanred to certain physiologic forms of stem rust, although it is susceptible under field conditions in the spring wheat area. The data for the two crosses are given in Table 2.

TABLE 2.—*Segregation of F_2 plants of Hope x Marquis and Hope x Reliance crosses in comparison with parents into frequency classes for stem rust infection at Mandan, N. Dak., in 1927.*

Stem rust percentage	Numbers of plants by infection classes: Hope x Marquis cross: Hope	F_2 hybrids	Marquis	Hope x Reliance cross: Hope	F_2 hybrids	Reliance
0	43	202		70	53	
Tr		91			15	1
10		69			10	9
20		18			8	14
30					2	25
40					1	12
50						6
60		42	50			
Total	43	422	50	70	89	67
Average	0	8	60	0	4	28

These data show that the immunity of Hope wheat in immune x susceptible crosses is inherited as a dominant character with approximately half the hybrid plants rust free in the F_2 generation.

IMMUNE X RESISTANT CROSSES

A Hope x Ceres cross will serve to show the reaction to stem rust of this group under field conditions. Ceres is a resistant selection from a Kota x Marquis cross. The data are given in Table 3.

TABLE 3.—*Segregation of F_2 plants of the Hope x Ceres cross in comparison with parents into frequency classes for stem rust infection at Mandan, N. Dak., in 1927.*

Stem rust percentage	Number of plants by infection classes: Hope	Hope x Ceres cross F_2 hybrids	Ceres
0	64	228	
Tr		182	
10		64	55
20		1	17
Total	64	475	72
Average	0	1	12

These data show that in the field the immunity of Hope wheat in immune x resistant crosses, as in immune x susceptible crosses, is inherited as a dominant character. It also was found that strains homozygous for immunity may be obtained in the F_3 generation. While a similar rust reaction has been obtained with certain physiologic forms of stem rust under controlled greenhouse conditions, this is the first instance of its occurrence under field conditions where one or many physiologic strains of the rust may be present.

It seems certain that most of the wheat breeding for rust control in the immediate future will be for rust immunity, using Hope or related strains as the immune parent. Hope wheat itself may not become important commercially, yet it should be only a matter of a comparatively few years until other new varieties having the immunity of Hope will be available for commercial growing. The development of Hope wheat and the evidence of the dominant inheritance of its immunity from stem rust in crosses with susceptible and resistant varieties is one of the most encouraging developments of recent years and should give a great impetus to breeding as a method for controlling black stem rust in the spring wheat states.

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INHERITANCE OF AWNS IN CROSSES INVOLVING SEVIER AND FEDERATION WHEATS[1]

GEORGE STEWART[2]

Until the last few years awn inheritance in wheat has been regarded as extremely simple, that is, as being dependent on a single factor difference. The awns of the F_1 plants have nearly always been intermediate in length between the aws of the two parents, with the F_2 ratios 3:1 or 1:2:1, awnlessness usually being regarded as dominant. Recently, however, it has become apparent that the inheritance of awns is much more complex than the original data indicated. Several workers have found two independent factors and one has found two factors segregating in such a fashion as strongly to suggest linkage between these two factors.

Howard and Howard (3)[3] in India crossed a fully bearded wheat with one described as being really awnless, a fact which they emphasized as important, inasmuch as many of the so-called awnless varieties really have short-tip awns. In the F_2, five awn-classes were obtained, *viz.*, (a) entirely awnless, (b) short tips, (c) long tips, (d) nearly full bearded, and (e) fully bearded. When the awned and partially awned plants were grouped together, there was a ratio of 15 awned to 1 entirely awnless. These results were explained on a two-factor basis. Four classes bred true, and when the short-tipped plants and the long-tipped plants were crossed, F_2 segregation showed some fully bearded and some awnless plants as well as the intermediate forms.

Clark (1) likewise found a somewhat complex condition in the inheritance of awns in a cross between Hard Federation and Kota. He made five classes of awn types in F_2 and arrived at the conclusion that segregation was too complex to be analyzed completely by the methods which he used. He partly established the presence of two major factors, however, although some of the data obtained at widely separated stations did not check well.

Nilsson-Ehle (5) obtained by mutation true-breeding forms of awnless, half-awned, and awned wheats. Awnless forms were partly dominant to half-awned and to awned, and half-awned forms to

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[2]Agronomist. The writer gratefully acknowledges the assistance of D. C. Tingey, Assistant Agronomist, and of D. E. Heywood and Harold Price, research assistants.

[3]Reference by number is to "Literature Cited," p. 170.

awned. He explained his results on the basis of multiple allelomorphs for half-awned and fully awned plants arising by complex mutation from the awnless plants.

A parallel case in rice has recently been reported by Jones (4) who found evidence of two independently inherited factors for awnedness. In a cross between a fully awned variety and an awnless one, the F_1 was intermediate. He obtained the data on the F_2 plants and grew a few F_3 progenies. He concluded that either of the two factors alone produced an intermediate condition and that the two together produced fully developed awns. He was unable to separate his two intermediate classes.

The writer (7) recently reported a strong indication of linkage between two factors for awnedness in a cross between Sevier and Federation wheats. A pure line of each parental variety was used and three F_2 families were used in the study. In two of the families kernels from all of the F_2 plants were sown for F_3 progeny rows. In the other case 74 F_3 families were grown, the F_2 plants from which these came being selected at random so far as awns were concerned.

There were four true-breeding classes, *viz.*, (a) fully awned, similar to the Sevier parent; (b) awnless, similar to the Federation parent; and (c) and (d) two intermediate classes. The true-breeding parental forms were regularly much more numerous than the true-breeding intermediate forms. The data obtained were explained by the theory of two factors so linked with each other as to give about 35% crossing over.

EXPERIMENTAL

The studies here reported involve two crosses, one of which was between a pure line of Federation and another pure line of Sevier from that used in the cross previously reported. This cross, made with the purpose of increasing desirable strains for wheat improvement work, offered a good opportunity for checking carefully awn inheritance. The other cross was between a pure line of Federation and a homozygous segregate (known as G-149) from the cross of Sevier x Dicklow. G-149 is fully awned, having received its awns from the Sevier parent. The purpose of this cross was to unite the higher rust resistance (7) of G-149 with the stiff straw and other desirable characters of Federation.

DESCRIPTION OF PARENTS

The parents used in these crosses were Federation, Sevier, Dicklow, and a homozygous segregate previously obtained from a cross of

Sevier x Dicklow. This segregate bears its nursery pedigree number, G-149.

FEDERATION

The variety Federation has great commercial importance in Oregon, in Idaho on irrigated land, and is now being brought into Utah where it is replacing the predominant variety Dicklow on land that suffers regularly from lodging. Federation has better standing ability and was chosen, therefore, as a parent to cross with Sevier whose standing ability is markedly weak. Federation has a distinct spring habit, matures somewhat earlier than Dicklow, is about 15 to 20 cm shorter of culm than Sevier and about 6 to 8 cm shorter than Dicklow.

Its spikes are awnless except for very short tip awns and an occasional apical awn, and the variety is classified by Clark, Martin, and Ball (2) as awnless. The spike is somewhat oblong, a trifle more dense than ordinary lax wheats, such as Marquis, and is borne erect. The glumes are dark bronze to brown and the kernels are white, soft, and short.

SEVIER

The variety Sevier (6) has commercial importance in the Sevier River Valley of Utah where there is some black stem rust occasionally. The straw is extremely weak and the grain lodges badly, although unless lodging is extremely severe there is little loss for Sevier seems to have a certain amount of resistance to the physiologic forms of *Puccinia graminis tritici* that occur in this region. It is extremely high yielding under favorable conditions, is somewhat drouth resistant, and is also thought to be slightly resistant to alkali, however, this has not been proved. The spike is awned and is somewhat laterally compressed. The glumes are bronze but not so dark as those of Federation. The kernels are white and in some pure lines are almost as hard as those of durum wheats, whereas in others the kernels are soft. The grain is held firmly in the chaff and no amount of weathering seems to cause shattering, a fact which makes it a desirable parent to use both with Federation and Dicklow as these two varieties both lose considerable grain if left standing in the field any length of time after maturity.

DICKLOW

Dicklow wheat possesses the spring habit of growth and is medium-late in maturing. The stems and leaves display a rather grayish-blue color just before maturity owing to a distinct glaucousness. The stems are rather strong and coarse and the leaves are broad. The

spikes are awnless, though short beards or beaks are rather common at the apex. The glumes are glabrous and white. The kernels are soft, white, and from short to midlong. The spikes vary from an erect to a nodding position. The shape of the spike most common to the variety is mid-dense, although many are clavate (clubbed at the apex).

G-149

G-149, a segregate from the cross Sevier x Dicklow, has not as yet been given a varietal name. It has the spring growth habit and moderately long slender culms which do not stand well. The spikes are fully awned. The glumes are glabrous and white. The kernels are semi-hard, white, and midlong. The spike is lax and held in a partially nodding position. The grain is held rather firmly in the spike. Careful tests (7) have shown G-149 to be highly resistant both in the field and in the greenhouse to all available forms of *Puccinia graminis tritici* E. & H.

SEVIER X FEDERATION

In 1923, Utah Station pure line No. 59 of the Sevier variety was crossed with a pure line of Federation. The F_1 plants were grown in 1924, spaced about 1 foot apart each way so as to permit the production of a large number of kernels. The awns were intermediate but apparently much shorter than half the length of the awns of the awned parent Sevier.

In 1925, the F_2 plants were grown in rod-rows 1 foot apart and spaced 3 or 4 inches in the row. There were 448 of these. They were classed into four groups and designated as of awn-class No. 1, awn-class No. 2, awn-class No. 3, and awn-class No. 4.

Awn-class No. 1 consisted of awnless plants similar so far as possible to the awnless Federation parent. Awn-class No. 2 consisted of plants with intermediate awns as similar to those of the F_1 as possible. Awn-class No. 3 was also intermediate but was rather distinct from awn-class No. 2 in that the apical awns were considerably longer and awn points were found extending farther down the spike. Awn-class No. 4 was fully awned and compared so far as possible with the fully awned Sevier parent.

As found in the previous study, accurate separation of all of the F_2 plants into their proper segregating classes was next to impossible. Separations in the F_2 were made merely as a matter of convenience, and the real data were obtained in F_3. In other words, it was much more accurate to sow 20 to 40 grains from each of the F_2 plants and determine the genotype of the F_2 plant from the F_3 progeny so

obtained than it was to classify the F_2 plants themselves. Therefore, this was the method of procedure.

In 1926, there were 448 progeny rows, each from a single head of an F_2 plant, grown 3 or 4 inches apart in rod-rows 1 foot apart. They were harvested by pulling the plants of each progeny row separately. Each progeny was properly labelled, carefully tied, and stored until winter when classification was made in the laboratory. At that time the 20 to 40 plants of each progeny row were classified into awn-class 1, 2, 3, or 4, and the row as a whole was used to determine the genotype of the F_2 plant from which the row was descended.

It turned out that the awns on many of the plants were broken during harvest and storage. This made classification less accurate than if it had been done in the field, but this was partly offset by the fact that the large number of plants made for a high degree of accuracy. Mounted specimens of spikes showing the range of each awn-class were kept continually on the table by the worker who was well-trained and who checked frequently with his material, with the mounted specimens, and with the writer. After all the plants of each separate progeny had been classified, the data were recorded and the entire progeny regarded as the true genotype of the one F_2 parent plant. When the data were completed, the F_2 plants were found to belong in the nine awn-classes shown in Table 1.

TABLE 1.—*The breeding behavior of 448 F_2 plants from a cross of Sevier x Federation as determined by their respective F_3 progenies—20 to 40 plants in each F_3 progeny, grown at Logan, Utah, 1926.*

(The numbers given represent the number of F_3 progenies falling into each of the nine awn-classes.)

Breeding behavior	Number of F_3 progenies
True breeding for	
Awns 1	53
Awns 2	20
Awns 3	18
Awns 4	39
Segregating for	
Awns 1, 2	55
Awns 1, 2, 3	49
Awns 1, 2, 3, 4	112
Awns 2, 3, 4	48
Awns 3, 4	53

According to the hypothesis advanced in a previous paper, two factors for awns were so linked as to allow 35% crossing over. These factors were designated as A(a) and T(t), and the fully awned parent (Sevier) assigned the genotype AATT and the awnless parent (Federation) the genotype aatt. The four gametes AT, At, aT, and

a t were thought to be produced in the ratio of 1.8:1:1:1.8, instead of 1:1:1:1 which is the case for two factors independently inherited. This would produce the theoretical combinations shown in Table 2.

TABLE 2.—*Theoretical number and sort of gametes produced in F_1 and the theoretical number and sort of zygotic combinations resulting in F_2 with two factors so linked as to give 35% crossing over.*

	1.8 A T	1.0 A t	1.0 a T	1.8 a t
1.8 A T	3.24 AA TT	1.8 AA Tt	1.8 Aa TT	3.24 Aa Tt
1.0 A t	1.8 AA Tt	1.0 AA tt	1.0 Aa Tt	1.8 Aa tt
1.0 a T	1.8 Aa TT	1.0 Aa Tt	1.0 aa TT	1.8 aa Tt
1.8 a t	3.24 Aa Tt	1.8 Aa tt	1.8 aa Tt	3.24 aa tt

(1) 3.24 AA TT	(6) 3.6 Aa tt
(2) 3.6 AA Tt	(7) 3.6 aa Tt
(3) 3.6 Aa TT	(8) 1.0 aa TT
(4) 8.48 Aa Tt	(9) 3.24 aa tt
(5) 1.0 AA tt	

Expected breeding nature of the nine genotypes

(1) Breed true for awns 4	(6) Segregate for awns 1, 2, 3
(2) Segregate for awns 3, 4	(7) Segregate for awns 1, 2
(3) Segregate for awns 2, 3, 4	(8) Breed true for awns 2
(4) Segregate for awns 1, 2, 3, 4	(9) Breed true for awns 1
(5) Breed true for awns 3	

It is seen from Table 3, which shows the closeness of fit by the X^2 method, that the degree of correspondence between the theory and the facts is very high. P=0.57, that is, in 57 cases out of 100 a worse fit due to chance alone might be expected.

TABLE 3.—*Calculated (C) and observed (O) number of F_2 plants in each awn-class as determined by the F_3 breeding behavior.*

Genotype	C	O	O–C	$(O–C)^2$	$(O–C)^2/C$
(1) AA TT	46.3	53	6.7	44.89	0.9695
(2) AA Tt	51.4	55	3.6	12.96	0.2521
(3) Aa TT	51.4	49	2.4	5.76	0.1121
(4) Aa Tt	121.2	112	9.2	84.64	0.6983
(5) AA tt	14.3	20	5.7	32.49	2.2720
(6) Aa tt	51.4	48	3.4	11.56	0.2249
(7) aa TT	14.3	18	3.7	13.69	0.9573
(8) aa Tt	51.4	53	1.6	2.56	0.0498
(9) aa tt	46.3	39	7.3	53.59	1.1574

X^2=6.6934
P=0.5705

FEDERATION X G-149

As already indicated, G-149 is a homozygous awned segregate from a cross between awnless Dicklow and awned Sevier wheats. The full awns of G-149 come from the Sevier parent and would probably behave in a similar fashion. This cross, made for wheat improvement purposes, afforded an excellent opportunity to study

inheritance of awns during the same operation that pure-breeding segregates were being obtained for preliminary yield tests. Since Federation had excellent straw and yielded well but shattered badly and was highly susceptible to black stem rust (*Puccinia graminis tritici*, E. & H.), it was a promising parental mate in a cross with G-149 which had good yielding powers, weak straw, high resistance to black stem rust, and which at the same time held the grain firmly in the spike.

In 1924 the cross was made between a pure line of Federation and a single plant of G-149. The next year the F_1 plants were spaced about 1 foot each way to permit a large development. The awns of the F_1 plants were intermediate in length but considerably less than half as long as those of the awned parent, G-149.

Two of the several well-developed F_1 plants were chosen as sources of seed for the F_2 progeny plants. The kernels were sown in rod-rows 1 foot apart and spaced 3 or 4 inches in the row. When the grain was nearly mature, the F_2 family that seemed to be on the most uniform soil was chosen for study. The plants were pulled separately and classified hurriedly into the four awn-classes already described. Classification was also made for chaff color as there was segregation for this character as well as for awns.

In 1927, the kernels from one head of each of the 638 F_2 plants were seeded in a single rod-row and spaced 3 or 4 inches apart. The order of seeding was by groups according to chaff color and awns. No particular effort was made to get genetic data in the F_2 since the F_3 progeny rows were to be studied as a means of obtaining true-breeding forms. From 20 to 50 plants were obtained in each progeny, though by far the larger number of rows contained from 35 to 40 plants. At harvest these were examined and the range of each awn-class studied. Mounts were prepared and kept constantly available for comparison.

In this cross the awn data were taken in the field. The writer and two well-trained assistants did all the work and repeatedly checked with each other. It is thought the combination of this careful procedure and of the use of the F_3 progeny test as a means of classifying F_2 plants made the classification both highly accurate and very nearly uniform throughout the various progenies. Only the awn data are here included for comparison with those obtained in the Sevier x Federation cross.

The plants of each row were classified according to the four awn classes. The breeding behavior of each progeny row was regarded as showing the genotpye of its parental F_2 plant. There was, there-

fore, careful classification of the plants in each row which showed the row to fall into one of the nine classes given in Table 2. The whole row was now regarded merely as one F_2 plant and each of 638 F_3 rows was so classified. The data are summarized in Table 4.

TABLE 4.—*The breeding behavior of the 638 F_2 plants as determined by their respective F_3 progenies—about 35 to 40 plants in each progeny, grown at Logan, Utah, 1927.*

(The numbers given are the number of F_3 progenies classified as falling into each of the nine awn-classes. Cross between Federation and a fully awned segregate (G-149) out of a cross between Sevier and Dicklow wheats.)

Breeding behavior	Number of F_3 progenies
True breeding for	
Awns 1	60
Awns 2	24
Awns 3	25
Awns 4	59
Segregating for	
Awns 1, 2	70
Awns 1, 2, 3	77
Awns 1, 2, 3, 4	171
Awns 2, 3, 4	75
Awns 3, 4	77

These observed figures were now studied by the X^2 method to see how the theory of two linked factors with about 35% crossing over fitted the data obtained. This study, reported in Table 5, shows a remarkably close fit, but not materially closer than the manner of attack, the careful procedure, and the use of properly grouped large numbers of F_3 progenies might be expected to give.

TABLE 5.—*Calculated (C) and observed (O) numbers of F_2 plants in each awn-class as determined by the F_3 breeding behavior.*

Genotype	C	O	O–C	$(O-C)^2$	$(O-C)^2/C$
(1) AA TT	65.90	60	5.90	34.8100	0.5282
(2) AA Tt	73.22	70	3.22	10.3684	0.1461
(3) Aa TT	73.22	77	3.78	14.2884	0.1951
(4) Aa Tt	172.48	171	1.48	2.1904	0.0127
(5) AA tt	20.34	24	3.66	13.3956	0.6586
(6) Aa tt	73.22	75	1.78	3.1684	0.0433
(7) aa TT	20.34	25	3.78	14.2884	0.1951
(8) aa Tt	73.22	77	4.66	21.7156	1.0676
(9) aa tt	65.90	59	6.90	47.6100	0.7225

$X^2 = 3.5692$
$P = 0.8904$

In this case $P = 0.89$. This indicates that the theory advanced fits the obtained data extremely well. If the experiment were repeated, a worse fit might be expected in 89 out of each 100 trials, due entirely to chance.

DISCUSSION

In the previous study of awn inheritance in a cross between Federation and Sevier wheats the first case of linkage between awn factors in wheat was indicated. The two crosses here reported were of such a nature as to confirm or to call into question the theory previously advanced, that is, that two factors for awns are so linked as to produce gametes in the proportion of 1.8:1:1:1.8, which amounts to a cross-over value of about 35%. Though conducted chiefly as practical projects in the production of new strains for wheat improvement, these two studies in hybridization were so handled as to yield reliable genetic data. Advantage was taken, therefore, to use the data for confirmation or refutation of the theory previously advanced.

In a former study, two classes segregating for awns had to be grouped together in two different parts of the segregation, namely, (a) the groups segregating for awn-classes 1 and 2 and for awn-classes 1, 2, and 3 had to be combined into one group; and (b) the groups segregating for awn-classes 2, 3, and 4 and for awn-classes 3 and 4 had to be combined into one class. Careful work with F_3 progenies permitted clear-cut separation in the present study, that is, all nine expected classes were now obtained in numbers very close to the calculated expectancy.

It is fully understood, however, that highly confirmatory though these data are, they merely render the hypothesis of linkage more likely. Proof of linkage has to be sought in other ways, as has already been pointed out (7). The following studies on this problem are now under way at the Utah station:

1. The two intermediate awn-classes have been crossed and the requisite generations are being grown.

2. F_1 plants are being obtained for back-crossing.

3. The awnless parent has been crossed with each of the two intermediate types.

The two studies, as conducted in these investigations, show that it is possible to separate the two intermediate awn types not only from parental forms but from each other as well. Moreover, this was done in the segregating F_3 progenies as well as in the true-breeding F_3 progenies. It was not possible correctly to classify every plant in the segregating F_3 progenies, but it was possible to make out what the nature of the segregation really was. It was possible to differentiate clearly between 1–2 segregation as opposed to 1–2–3 segregation and also between 2–3–4 segregation as opposed to 3–4 segregation.

It seems evident, therefore, that the two major factors here called A(a) and T(t) produced different effects, capable of being visibly separated under proper working conditions.

SUMMARY

1. Awn inheritance has during the last few years been found to be much too complex in several crosses to be explained by the difference of a single factor. Several cases of two independent factors are reported. A very recent study of a Sevier x Federation cross by the writer indicated two linked factors for awns.

2. Two other crosses are studied in this paper for awn segregations, namely, a pure line of Federation by a different pure line of Sevier from the one previously used, and a pure line of Federation by a single plant of a fully awned segregate (G-149) out of a cross of Sevier (awned) x Dicklow (awnless). Data from such crosses should confirm or refute the previously advanced theory of two factors for awns so linked as to give about 35% crossing over.

3. It was found much more accurate to obtain the genotype of the F_2 plants by their breeding behavior in F_3 than by eye-classification of the F_2 plants themselves. It should be emphasized that the F_3 progenies of *all* the F_2 plants were grown and studied in detail in the laboratory in one cross and in the field in the other. It is important also that such large numbers as 448 F_3 progenies were grown in one case and 638 in the other. The population of 20 to 50 (usually 35 or 40) plants in each F_3 progeny was sufficient to show the nature of the segregation where segregation occurred, or to establish homozygosity for the awn character.

4. The work was done by well-trained workers who kept at hand for constant reference mounted specimens showing the range of each awn-class. These workers also checked frequently with each other so as to achieve uniformity among themselves.

5. The data obtained confirm the theory previously advanced for this cross, *viz.*, two factors for awns so linked as to yield F_1 gametes in the ratio of 1.8:1:1:1.8, i.e., about 35% crossing over. In both crosses the X^2 method for closeness of fit showed remarkably good fits, P being 0.57 and 0.89, respectively, for the two cases.

6. These two studies in connection with the previous one indicate very strongly that the theory previously advanced at least approximates correctness. Absolute proof of linkage has to be obtained by other methods. Work on this proof is now under way.

7. Finally, these studies have made clear that the two factors when present separately each produces a different, but somewhat

equal, major effect. The effects of the two factors could be identified not only in the true-breeding F_3 progenies but also in the segregating ones.

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A WHEAT VARIETY SURVEY IN WASHINGTON[1]

E. G. SCHAFER AND E. F. GAINES[2]

INTRODUCTION

A knowledge of wheat varieties and the location in which they are grown is essential in carrying out a program for the improvement of the crop. On account of wide variations in elevation, temperature, rainfall, and character of soil in Washington, many varieties have been introduced to meet the needs of the different wheat-growing areas. The grower, in search of superior varieties, often discards one variety for another and further adds to the number grown. In some cases he finds later that he has substituted a poor variety for a good one, and also in changing from one to another has increased the chances for mixture.

A variety dist'nctly superior to others may be introduced with marked advantage, particularly if it can replace more than one variety. It raises the standard by substituting the better for the inferior variety and reduces the chance for mixture. The work of wheat improvement is in part based on adaptation tests conducted at the main and branch stations and can be carried on more intelligently through information obta'ned on variety distribution by means of a variety survey.

WHEAT SURVEYS PRIOR TO 1926

A wheat variety survey for the crops of 1918 and 1919 was published in Washington Station Bulletin 159. The 1921 survey was published in THE WASHINGTON FARMER, December 28, of that year. A summary of the surveys for 1922 and 1923 is presented here as a permanent record and for comparison with the distribution of the 1926 crop.

SURVEY FOR THE 1926 CROP

Information necessary for making the survey concerning varieties grown, production, and acreage was secured direct from farmers by correspondence. The mailing list was obtained from county agents, grain dealers, and others acquainted with wheat growers within the various counties. The following form was used:

[1]Contribution from the Washington Agricultural Experiment Station, Pullman, Washington, as scientific paper No. 141. Received for publication December 23, 1927.

[2]Agronomist and Ceralist, respectivelv.

Dear Sir :

We desire to make a wheat variety survey for the State of Washington. We want to secure first hand information from wheat growers and would like to have your help. Will you please fill out the blank form below for the varieties you grew in 1926 and return it to us in the inclosed envelope as soon as possible? Mark with an X the variety you consider best adapted for your farm.

Varieties grown in 1926	Total number of bushels	Number of acres
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
Name	Postoffice	County

When this material is summarized and published, do you wish a copy?........

This form, in addition to requesting information about varieties grown, production, and acreage, asks the farmer's opinion as to the best variety for his farm and if he desires to receive the summarized report of the survey. This, and a stamped, self-addressed envelope, brought a larger percentage of returns than otherwise would have been expected.

Usable reports were received from 1,096 of the 3,805 farmers to whom the questionnaire was sent. A total of 5,865,451 bushels was reported, representing 14.6% of the total wheat grown in the state. In arriving at the final results of the survey, it was assumed that the growers reporting in each county were representative of all the growers of their respective counties.

After the reports had been received, they were grouped according to counties. The varieties with their acreage and production were then listed separately. The total wheat production for the state was secured from the 1926 Yearbook of the United States Department of Agriculture. The data on distribution by counties were taken from the 1919 United States Census Report. From these sources of information the total area and total production of each variety in each county were computed. A partial failure in the spring wheat areas in 1924 made the census figures for that year unsuitable for comparison. The amount and proportion of spring and winter wheat grown in 1926 was very similar to that of 1919. The use of the census data for that year lessened the error in computing the total yield of each variety in each county.

The computations necessary to secure production in bushels of a variety for a county were based on two proportions as follows: First, a : b :: c : x for obtaining the distribution of wheat by counties in 1926 in accordance with the 1919 distribution which was given in

bushels by counties in the 1919 Census; and second, which is dependent upon the first, d : e :: f : y, for securing the total number of bushels of a variety in the county for 1926. In the first proportion, *a* equals *bushels in the state for the 1919 Census*, *b* equals *bushels in county for the 1919 Census*, *c* equals *bushels in state for 1926* as given in Yearbook, and *x* equals *bushels in county for 1926*. In the second, *d* equals *bushels in survey in county*, *e* equals *total bushels in county for 1926* as found in the first proportion, *f* equals *bushels of variety in survey for county*, and *y* equals *total bushels of variety in county*. In the proportion a : b :: c : x, $x = \frac{cb}{a}$. Since *x* in the first proportion is equal to *e* in the second, its equivalent may be substituted directly for *e*, and the proportion reads $d : \frac{cb}{a} :: f : y$, or $y = \frac{f(\frac{cb}{a})}{d}$.

Using, for example, Baart in Adams County and substituting values from census report, yearbook, and survey, as indicated above, the formula appears as follows: $y = \frac{488{,}127\left(\frac{40{,}271{,}000 \times 3{,}910{,}240}{41{,}337{,}900}\right)}{577{,}047}$.
Solving the equation, y = 3,182,588, which is the number of bushels of Baart for Adams County. In securing this result, the calculation was carried to the fourth place when dividing the equivalent of *c* by the equivalent of *a* before multiplying by *b*, and to the second place when dividing the equivalent of $\frac{cb}{a}$ by the equivalent of *d* before multiplying by *f*. The production of other varieties in the same and other counties was obtained in a similar manner. The acreage of each variety for each county was also computed in like manner.

In the 1926 survey, 12 of the varieties listed in Table 1 were reported under two or more names. The names of these varieties with their synonyms follow:

Name	Synonym
Dicklow	Thompson Club
Red Russian	Australian Club
Fortyfold	Gold Coin
Hybrid 123	Red Hybrid
Hybrid 128	White Hybrid
Selection C	Smutless
Quality	Burbank (spring)
Jones Fife	Super and Burbank (fall)
Coppei	Red Walla
Martin	Amber and Martin Amber
Poole	Harvest King
Bluestem	White Elliott

TABLE 1.—*Summary of Washington wheat variety survey.*

Variety	1922 Bushels	1922 Percentage of crop	1923 Bushels	1923 Percentage of crop	1926 Bushels	1926 Percentage of crop
		Spring Wheats				
Baart	2,872,870	8.9	8,969,180	14.7	8,324,790	20.7
Bluestem	1,922,297	6.0	5,121,561	8.4	3,623,813	9.0
Jenkin	1,209,997	3.8	2,385,339	3.9	2,388,649	5.9
Marquis	983,498	3.1	2,965,755	4.8	2,158,063	5.4
Federation	3,840	0.01	2,056	—	1,933,510	4.8
Hybrid 123	926,943	2.9	857,814	1.4	1,361,755	3.4
Red Chaff	265,754	0.8	702,462	1.1	1,129,904	2.8
Dicklow	321,430	1.0	305,439	0.5	656,422	1.6
Hard Federation	32,963	0.1	86,433	0.1	501,038	1.2
Quality	17,104	0.05	75,000	0.1	166,615	0.4
White Federation	—	—	—	—	165,385	0.4
Bunyip	—	—	—	—	75,466	0.2
Red Bobs	—	—	—	—	72,127	0.2
Early Triumph	—	—	—	—	50,454	0.1
Little Club	194,968	0.6	90,325	0.1	5,708	0.01
Spring total	8,751,664	27.3	21,561,374	35.2	22,613,699	56.2
		Winter Wheats				
Triplet	2,164,786	6.7	6,048,063	9.9	4,229,408	10.5
Turkey	6,051,243	18.8	8,717,681	14.2	3,393,715	8.4
Hybrid 128	6,241,522	19.4	9,263,953	15.1	3,199,239	7.9
Fortyfold	2,331,501	7.3	5,336,364	8.7	2,296,683	5.7
Ridit	—	—	—	—	893,291	2.2
Jones Fife	1,124,713	3.5	2,226,571	3.6	583,256	1.4
Coppei	1,341,493	4.2	2,990,980	4.9	517,194	1.3
Hybrid 143	294,507	0.9	1,071,052	1.7	487,629	1.2
Red Russian	1,149,065	3.6	2,389,638	3.9	334,661	0.8
Selection C	—	—	—	—	248,892	0.6
Kanred	64,988	0.2	115,502	0.2	223,014	0.6
Martin	100,165	0.3	92,583	0.2	37,641	0.1
Poole	46,688	0.1	—	—	40,399	0.1
Allen	74,344	0.2	—	—	29,260	0.1
Hybrid 63	219,790	0.7	—	—	—	—
Winter total	21,204,805	66.1	38,252,387	62.5	16,514,282	41.0
Total in survey	29,956,469	93.4	59,813,761	97.7	39,127,981	97.2
Total in state	32,104,000	100.0	61,215,000	100.0	40,271,000	100.0

VARIETY DISTRIBUTION

The county distribution of wheat varieties in bushels, obtained in the manner described above, is shown in Figs. 1 and 2 on the outline maps of the wheat-growing areas of Washington. The total production and percentage of each variety grown in 1926 is shown in summary form in Table 1, along with similar data for the surveys of 1922 and 1923. The total given for all varieties is less than the

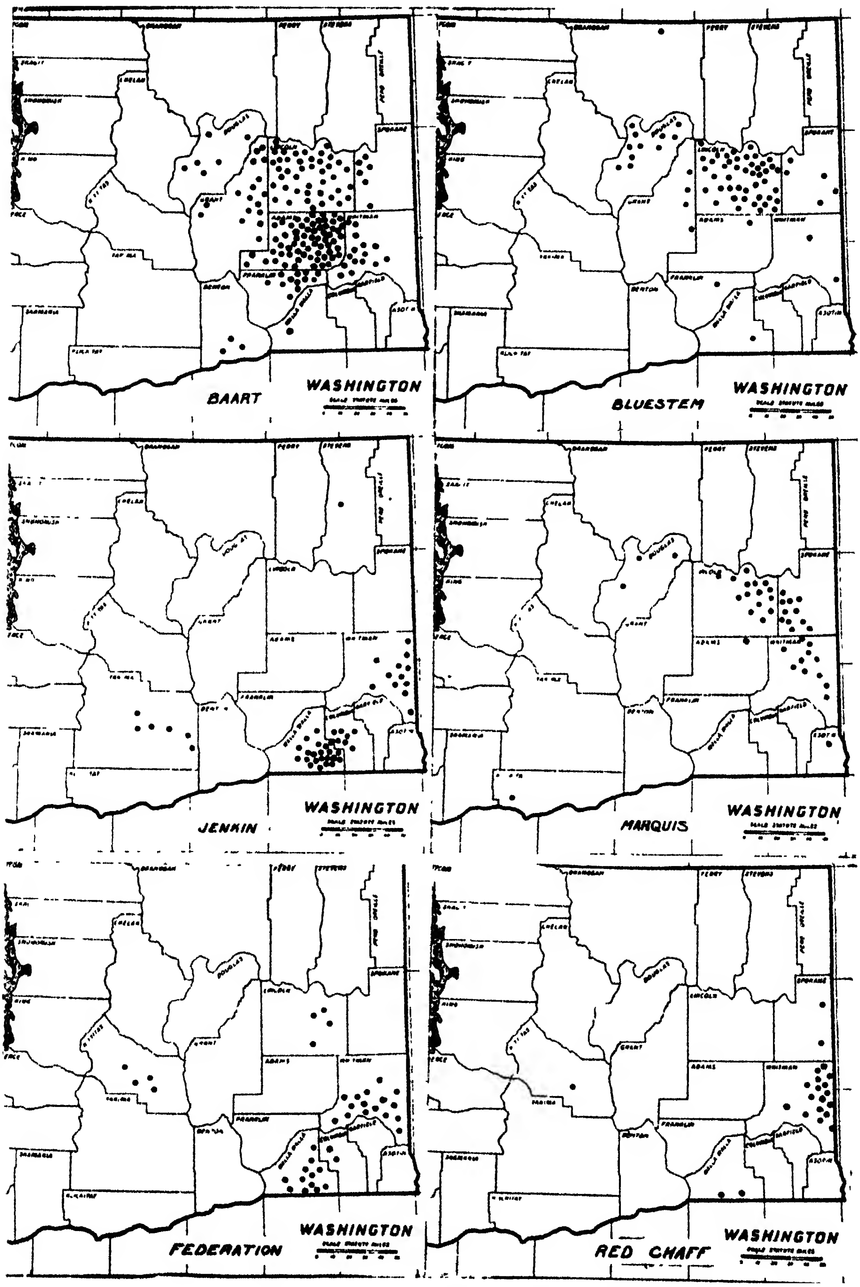

FIG. 1.—Location of the six leading spring wheats of Washington. Baart, 8,325,000 bushels; Bluestem, 3,624,000 bushels; Jenkin, 2,389,000 bushels; Marquis, 2,158,000 bushels; Federation, 1,934,000 bushels; and Red Chaff, 1,130,000 bushels. Each dot equals 50,000 bushels.

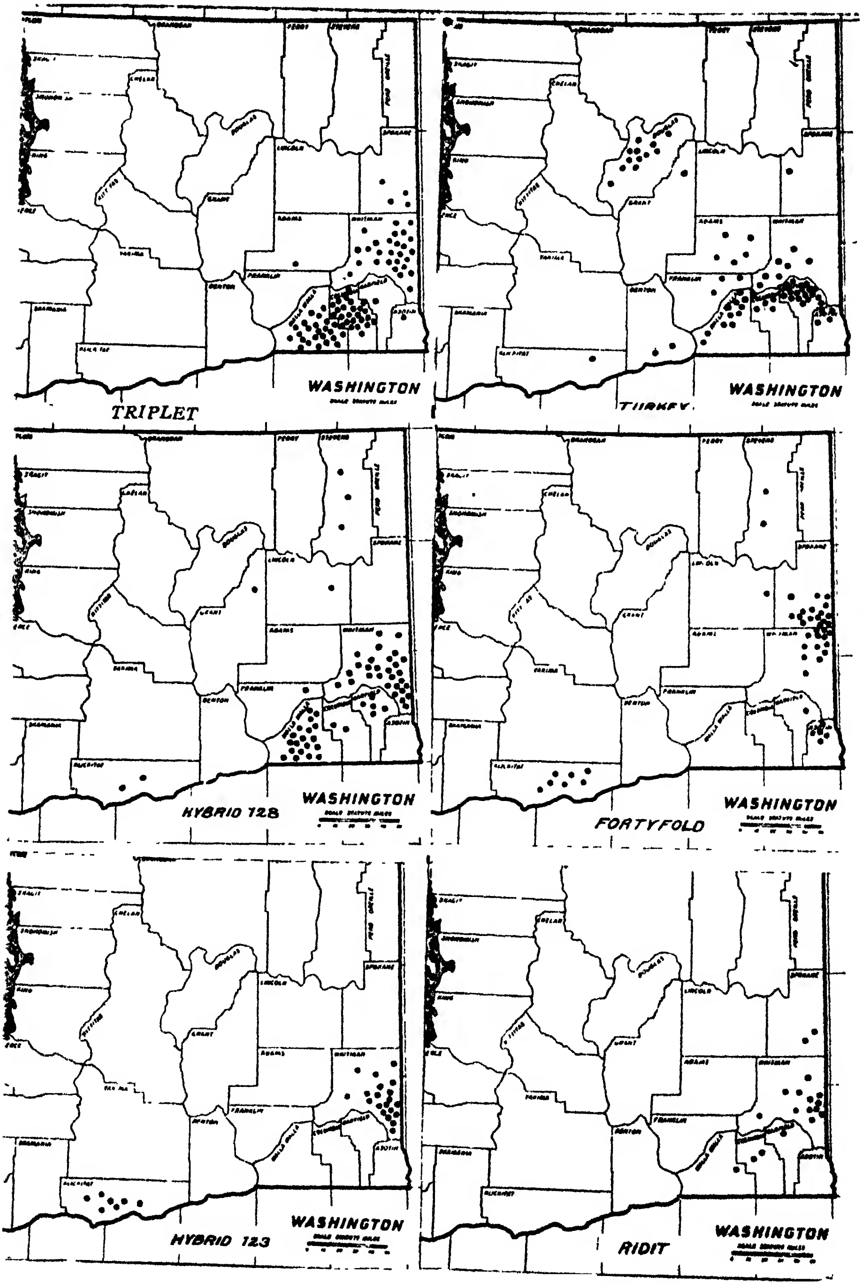

FIG. 2.—Location of the six leading winter wheats of Washington. Triplet, 4229,000 bushels; Turkey, 3,394,000 bushels; Hybrid 128, 3,199,000 bushels; Fortyfold, 2,297,000 bushels; Hybrid 123, 1,362,000 bushels (also grown as spring wheat); and Ridit, 893,000 bushels. Each dot equals 50,000 bushels.

total in the state, since counties producing less than 50,000 bushels were not included and small amounts were lost in the computations by dropping minor fractions. There is a large variation in the total amount of wheat produced from year to year, as well as a fluctuation in the proportion of spring and winter wheat raised. In 1926 the amount of spring wheat exceeded the winter wheat by 6,099,417 bushels. The acreage of spring wheat is increased if the preceding

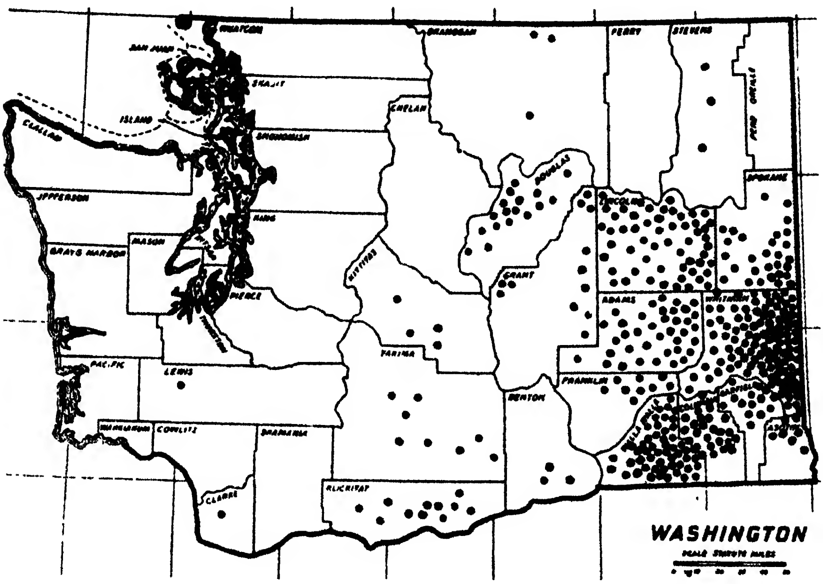

FIG. 3.—Outline map of Washington showing distribution of wheat in 1926. Estimated production 40,271,000 bushels. Each dot equals 100,000 bushels.

fall is unfavorable for sowing or if there is much winter killing. The yield per acre is influenced by spring rains and weather conditions during harvest. On the average, about 40% of the Washington wheat crop is sown in the spring. The wheat land of the state is mainly in eastern Washington, as shown in Fig. 3 which gives the distribution of all wheat.

From this survey it was found that 30 different varieties were grown. Photographed heads of the most important ones are shown in Figs. 4 and 5. Baart led all varieties in 1926 with 20.7% of the crop. Other spring varieties ranked as follows: Bluestem, 9.0%; Jenkin, 5.9%; Marquis, 5.4%; Federation, 4.8%; Hybrid 123, 3.4%; and Red Chaff, 2.8%. No other spring variety produced as much as 2%. Of the winter varieties, Triplet constituted 10.5% of the entire crop; Turkey, 8.4%; Hybrid 128, 7.9%; Fortyfold,

5.7%; and Ridit, 2.2%. Thus, seven spring and five winter varieties produced 86.7% of the entire crop in 1926.

The five varieties Dicklow, Hard Federation, Jones Fife, Coppei,

FIG. 4.—Leading spring wheats. Left to right, Hybrid 123, Federation, Marquis, Jenkin, Bluestem, and Baart.

and Hybrid 143 each comprised between 1 and 2%. The other 12 varieties represent less than 4% and might wisely be discontinued, as a large number of varieties even in small quantities tends to increase mixtures and aggravate marketing difficulties.

In certian varieties there has been a great change in the amount grown during the time that elapsed from the first survey in 1918 to the survey that was made in 1926. At the beginning of this

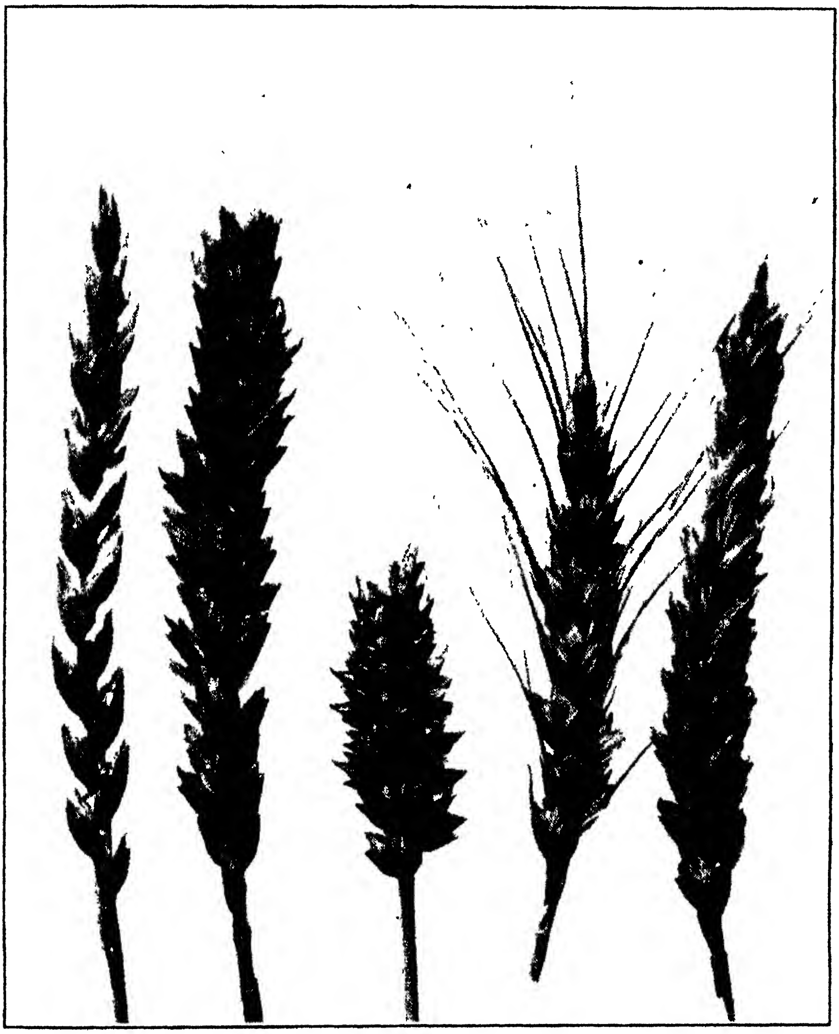

FIG. 5.—Leading winter wheats. Left to right, Ridit, Fortyfold, Hybrid 128, Turkey, and Triplet.

period Red Russian comprised 6.2% of all wheat in the state, but in 1926 it had dropped to less than 1%. Triplet was not produced commercially in 1918, but was grown in increasing amounts in the years of each succeeding survey. In 1921 it comprised 3% of the crop;

in 1922, 6.7%; in 1923, 9.9%; and in 1926, 10.5%. It stood first among the winter varieties and exceeded Turkey by 800,000 bushels. Ridit has increased rapidly since its introduction in 1923 and gives promise of occupying a much more important place in the near future.

Of the spring wheats, Baart was unknown to the grain trade 15 years ago. Its early maturity, drought resistance, good yielding ability, and superior quality have caused it to be increased until it now occupies more than three-tenths of the entire wheat acreage of Washington. Section after section of Adams, Grant, and Lincoln Counties produces no other variety. It has crowded out Bluestem and Marquis in areas of less than 15 inches of rainfall. Federation has been increased rapidly since 1924 in areas having more than 15 inches of rainfall.

Many wheat varieties have succeeded well in the state, but those that are least well suited are gradually being replaced by superior ones which have been introduced or developed.

COMPARATIVE WORTH OF VARIETIES AS INDICATED BY FARMERS' CHOICE

Of the 1,096 farmers reporting, approximately one-half expressed a variety preference. In some cases only the preferred variety was being grown, while in other cases additional varieties were listed. In analyzing these data, the choice expressed was entered in the "for" column if a variety were favored, while the decision was entered in the "against" column if the choice expressed were for some other variety which was also being grown. Spring and winter va-

TABLE 2.—*Varietal adaptation as expressed by farmers.*

Variety	Number		
	For	Against	Difference
Spring Wheats			
Baart	118	13	105
Bluestem	40	54	—14
Jenkin	40	3	37
Marquis	42	18	24
Federation	40	12	28
Hybrid 123	16	5	11
Red Chaff	3	6	—3
Dicklow	8	3	5
Winter Wheats			
Triplet	41	25	16
Turkey	92	13	79
Hybrid 128	40	26	14
Fortyfold	43	21	22
Ridit	33	13	20

rieties were each considered independently. The results are shown in Table 2.

An expressed choice of "for" may be taken as an indication that the farmer making such choice finds the variety more suitable for his needs than other varieties and would thus be expected to continue growing it. If the opinion of a grower is registered as "against," it may be assumed that he favors some other variety and thus may be expected to discard the less favorable one. A negative "difference" shows that a variety is not firmly established in certain parts of the area which it occupies. Table 2 should aid in determining the varieties which will likely be increased and those which will be grown less extensively, and should show, when studied in its county aspects, where such increases and decreases will be expected.

MEDIAN TERMS IN ADJECTIVES OF COMPARISON[1]

CARLETON R. BALL, *Chairman* (ARVICULTURE, BOTANY), HOMER L. SHANTZ (ECOLOGY, PHYSIOLOGY), AND CHARLES F. SHAW (EDAPHOLOGY)[2]

The enormous development of plant breeding following the rediscovery of the primary laws of genetics has had one unexpected result. It has brought about a need for median terms in a series of three adjectives of comparison. In most hybrids the parents have one or more pairs of contrasting characters. Precise terms are needed to describe those intermediate for each such pair of characters. Short organisms are crossed on tall, thin on thick, smooth on rough, acute-angled on obtuse, glabrous on hairy, hornless on horned, etc. How shall the intermediates be designated?

The common practice at present is to speak of them as "medium." If only one character pair is concerned in any given paper or discussion, there will be no doubt of the meaning of "medium." Where several character pairs are discussed in one paper the use of "medium" becomes very confusing. The reader is always glancing back or hunting tediously to find out for what particular factor the plant is "medium," or intermediate.

It always is possible to achieve clearness by using a phrase instead of a word. One can say, "The plants intermediate for awn length," or "The animals intermediate for coat color," etc. How much better to be able to say it in a single word and how much clearer to have the single word tell exactly for what character pair the given organism was intermediate, or ' medium."

It must not be supposed that the need for such comparisons is confined to genetic and breeding papers. By no means is this true. There are comparisons of color, size, form, weight, structure, etc., in geology, edaphology, physics, and astronomy, just as much as in biology. There are contrasts in climate, requiring comparison of temperature, moisture, humidity, wind velocity, pressure, etc. Wherever there is comparison there is the need for a median term to express the intermediate position.

[1]Presented at the Annual Meeting of the Society in Chicago, Ill., Nov. 17, 1927, by the Committee on Agronomic Terminology as a part of their annual report. Reprints of this report may be had on application to the Chairman of the Committee.

[2]Senior Agronomist in Charge, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.; Head Department of Botany, University of Illinois, Urbana, Ill.; and Head, Division of Soil Technology, College of Agriculture, University of California, Berkeley, Calif., respectively, members of the Committee on Agronomic Terminology.

Thinking and discussion along this line were begun by the senior author in 1923, in collaboration with the late Dr. C. V. Piper, whose untimely death prevented an earlier contribution on this topic. In deciding upon a desirable median term, the first task is to discover the root word for the basic character in the comparison expressed in the extremes. For instance, if the terms paired are "low" and "high," it is obvious that "height" is the basic character. In the

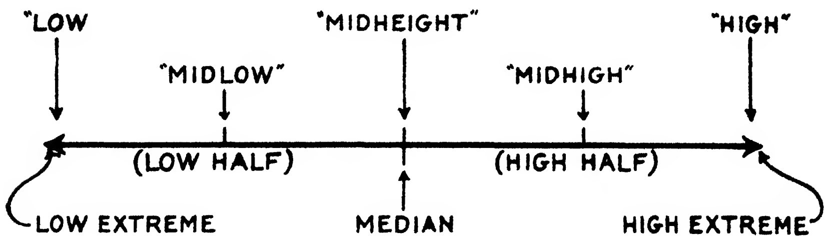

FIG. 1.—Diagram showing correct relation of extreme and median terms in comparison and illustrating why neither extreme term can be used as the root for the median term.

same way, if "light" and "heavy" and "slow" and "fast" are contrasting pairs, it is plain that "weight" and "speed," respectively, are the basic characters concerned. Discovering or inventing a satisfactory basic term is not always as simple as might be thought.

When the proper basic term has been discovered, the median term is formed simply by prefixing "*mid*" to the basic root. Examples as used above are low, midheight, high; light, midweight, heavy; and slow, midspeed, fast. In actual use, one may speak of the low plants, the midheight plants, or the high plants; likewise of light animals, midweight animals, and heavy animals. So a soils man would speak of a light soil, a midtexture soil, or a heavy soil. The advantage of a self-explaining median term is as obvious as the advantage of a self starter on an automobile.

Early in this investigation, one very common error of usage became apparent. This was the tendency to use one of the extremes as the root for the median term. For instance, reference would be made to low, "mid*high*," and high plants, or light, "mid*heavy*", and heavy animals. Oftentimes median terms so constructed are very plausible and may sound better or more correct than the true median term. Luckily, there is one easy and infallible test for such cases. Construct a diagram like that in Fig. 1 and insert the series of comparative terms under consideration.

It becomes apparent at once that "midheight" (middle of the height or median point in height) is the proper and accurate term

for the true middle between the two extremes. It is equally apparent that "midlow" is the middle point for the "low half," and "midhigh" the middle point for the "high half", and that neither ever can be the middle point between the two extremes. This test should be applied to every median term it is desired to employ. Thus only can unfortunate errors be avoided.

Series of adjectives of comparison have been assembled in several major devisions or subjects, as follows:

A. Dimension, distance, and abundance,
B. Time, age, and development,
C. Light, color, and sheen,
D. Sensations,
E. Other conditions and qualities.

Under each general division or subject are several to many subdivisions or subtopics. After each subtopic are given one to several comparisons. It is not intended that the lists shall be complete, either as to divisions, subdivisions, or comparisons. Other desirable ones will occur to every reader. It is hoped, however, first, that sufficiently numerous examples have been given to demonstrate the need and make plain the possibilities, and, second, that the method of determining correct usage and devising the needed median term has been made clear.

In the tables are given the existing basic term and any new terms proposed, and the three comparative adjectives, namely, the lesser extreme, the median term, and the greater extreme. Proposed new basic terms and the corresponding new median terms are printed in heavier type for the sake of emphasis. Criticisms, suggestions, and additions will be welcomed by the Committee.

These comparisons are quite independent of those of degree, as good, better, best; large, larger, largest; cold, colder, coldest, etc.

The adjectives of comparison for dimension, distance, and abundance are given in Table 1.

Only two new basic terms are proposed, namely, **"plumpth"** and **"thickth,"** in place of plumpness and thickness. "Plumpth" and "thickth" seem peculiar and the latter somewhat harsh at first sound. Width and breadth, and especially length and strength, would sound the same way if we had not become familiar with them in childhood.

Stouth, suggested in place of stoutness, is not a new word. It was in use when stout meant vigorous, and even violent, and not plump or fat. All it needs here is to be recognized in its new meaning, synonymous with stoutness.

TABLE 1.—*Adjectives of comparison for dimension, distance, and abundance, showing basic term, lesser extreme, suggested median term, and greater extreme.*

Basic term		Terms of comparison		
Present	Proposed	Lesser extreme	Median	Greater extreme
		Dimension		
size		small little dwarf tiny	midsize	large big giant enormous
height		low	midheight	high
stature		short	midstature	tall
length		short	midlength	long
width		narrow	midwidth	wide
breadth		narrow	midbreadth	broad
stoutness	stouth	slender	midstouth (midstoutness)	stout
thickness	**thickth**	thin	**midthickth** (midthickness)	thick
plumpness	**plumpth**	shrunken lean	**midplumpth** (midplumpness)	plump fat
depth		shallow	middepth	deep
		Distance		
position	stance	near contiguous adjacent close	midstance (midposition) (middistance)	far non-contiguous remote distant
space	space	close adjacent	midspace	open distant
		Abundance		
density		lax sparse	middensity	dense abundant
number		few	midnumber	many
distribution		sparse	middistribution	abundant
abundance		sparse	midabundance	abundant
fullness	fulth	empty	midfulth	full

Fulth also is a good word with dictionary standing, comparable to health, wealth, illth, etc. Its meaning is evident as a direct synonym of fullness.

Stance likewise is not a new word, but has the meaning of place, position, or situation. Midstance is shorter and simpler than middistance or midposition and is recommended.

In using the paired adjectives for which median terms are herein proposed, considerable latitude commonly exists both as to which of two or more pairs shall be chosen and also as to the actual components of a pair. Each of the four pairs listed under "size" is composed of the two words commonly used together, as *small* and *large*, *big* and *little*, *dwarf* and *giant*. Of the four pairs listed under "position," this is not equally true. One may say *near* and *far*, or *near* and *distant*, or *near* and *remote*, and so on. The chief obligation is to choose pairs which express the desired meaning clearly and accurately.

In Table 2 are given some adjectives of comparison for time (period), age, and development. No new basic terms are proposed. The median terms all are simple and most of them are in present use. Of most interest to agronomists are the ones dealing with season, age, growth, and development.

TABLE 2.—*Adjectives of comparison for time, age, and development, showing basic term, lesser extreme, suggested median term, and greater extreme.*

Basic term	Terms of comparison		
	Lesser extreme	Median	Greater extreme
period	ancient remote	medieval	modern recent
time season	early early	midtime midseason	late late
summer	spring	midsummer	autumn fall
winter	autumn fall	midwinter	spring
day	morning sunrise dawn	midday	evening sunset dusk
	morning	noon	night
night	evening sundown dusk	midnight	morning sunrise dawn
	new		old
age	young juvenile	midage	old senile
growth	seedling young	midgrowth	adult old
development maturity	green immature	midmaturity	ripe mature

Table 3 contains adjectives describing the various phenomena of light, color, and sheen. Two new basic terms, **"lux"** and **"umblux,"** are proposed. The first, "lux", is the Latin for light. With the prefix *mid*, it makes an excellent median term for several pairs of adjectives. The second new term, "umblux," is devised to indicate a mixture of light and shadow (as in a painting or in life), or of clearness and cloudiness of sky. It is merely a compound of the Latin *umbra*, meaning shade or shadow, from whence our English "umbrage" and "umbrella," and the Latin *lux*, meaning light. The median term, "midumblux" serves well.

TABLE 3.—*Adjectives of comparison for light, color, and sheen, showing basic term lesser extreme, suggested median term, and greater extreme.*

Basic term		Terms of comparison		
Present	Proposed	Lesser extreme	Median	Greater extreme
		faint		bright
light	**lux**	dim	**midlux**	clear
		dark		bright
		weak	(midintensity)	light
			(midstrength)	strong
		dim		clear
clarity		cloudy	midclarity	clear
		turbid		clear
		opaque		translucent
Light and		cloudy		clear
shadow (sky)	**umblux**	shady	**midumblux**	sunny
		gray		blue
		faint		conspicuous
		dull		bright
color		pale	midcolor	sharp
		light		dark
		weak		strong
				bright
		faint		conspicuous
tint		light	**midtint**	dark
		weak		strong
		faint		conspicuous
mottling	motley	obscure	midmotley	clear
		weak		strong
		dull		bright
sheen		opaque	midsheen	lucid
				shining

The term "motley" for a mixture of colors is very old. The median term, "midmotley," for a medium expression of mottling by the mosaic diseases of plants, was suggested by the senior author to Dr. Robert W. Webb, and has been used by him.[3]

The adjectives relating to the five senses, sight, hearing, taste, smell, and touch, given in Table 4, need little comment. The basic term tact, from the Latin *tactus*, touch, whence contact, tactless, tactual, etc, has the accepted meaning of physical or mental touch. The proposed median term, midtact, explains itself.

TABLE 4.—*Adjectives of comparison for sensations, showing basic term, lesser extreme, suggested median term, and greater extreme.*

Basic term		Terms of comparison		
Present	Proposed	Lesser extreme	Median	Greater extreme
sight		dim		clear
vision		faint	midvision	keen
				sharp
		dull		clear
		faint		distinct
sound		low		loud
tone		weak	midsound	full
		low	midtone	high
		sweet		harsh
		soft		hard
pitch		low	midpitch	high
		good		bad
taste		sweet	midtaste	sour
		sweet		bitter
odor		weak	midodor	strong
smell		faint	midsmell	pungent
		pleasant		nauseating
touch		faint		clear
contact	tact	weak	midtact	strong
		agreeable		disagreeable

In Table 5 are presented many series of adjectives of comparison for various conditions and qualities not so readily classifiable into groups. Most of them require no comment. There are several new basic terms and corresponding median terms which must be explained.

[3]WEBB, ROBERT W. Soil factors influencing the development of the mosaic disease in winter wheat. Jour. Agr. Res., 35: 587–614. 1927.

TABLE 5.—*Adjectives of comparison for various conditions and qualities, showing basic term, lesser extreme, suggested median term, and greater extreme.*

Basic term		Terms of comparison		
Present	Proposed	Lesser extreme	Median	Greater extreme
strength		weak tender fragile	midstrength	strong tough tenacious
weight		light	midweight	heavy
speed		slow	midspeed	fast rapid
force		weak	midforce	strong
power			midpower	
pressure		low light	midpressure	high heavy
tension		lax loose	midtension	tense tight
tenacity		deciduous caducous fragile	midtenacity	adherent tenacious ductile
flexion		limber flexible tender	midflexion	stiff rigid tough
consistence (soil, snow, fertilizer, etc.)		rare loose friable soft light	midconsistent	dense compact firm hard heavy
texture (soils, etc.)		amorphous powdery fine granular	midtexture	crystalline granular coarse cloddy
(fabrics)		fine loose smooth	midtexture	coarse tight rough
(endosperm)		starchy	midtexture	corneous horny
tilth		bad poor	midtilth	good
porosity		nonporous	midporosity	porous
perviousness		impervious	midperviousness	pervious
permeability		impermeable	midpermeable	permeable

TABLE 5.—*Continued.*

Basic term		Terms of comparison		
Present	Proposed	Lesser extreme	Median	Greater extreme
roughness		flat		ridged
rugosity	**rugaplane**	smooth	**midrugaplane**	rough
wrinkledness		plane		wrinkled
smoothness		rough	midrugaplane	smooth
		ridged		plane
angle		acute	midangle	obtuse
edge		sharp	midedge	dull
				blunt
straightness	**straighth**	straight	**midstraighth**	crooked
		straight		curved
		dry		wet
moisture		arid	midmoisture	humid
		desiccated		saturated
humidity		low	midhumidity	high
		low		high
temperature	temper	cold	midtemper	hot
		cool	(midtemperature)	warm
		minimum	optimum	maximum
coolness	**coolth**	cool	**midcoolth**	cold
warmth		warm	midwarmth	hot
wealth		poor	midwealth	rich
health		ill	midhealth	well
		sick		
illness	illth	well	midillth	ill
misfortune		good	midfortune	bad
goodness	**goodth**	bad	**midgoodth**	good
chemical		alkaline		acid
reaction		sweet	neutral	sour
susceptibility	**ceptisist**	resistant	**midceptisist**	susceptible
resistance	**ceptisist**	susceptible	**midceptisist**	resistant
immunity	**ceptimmune**	susceptible	**midceptimmune**	immune

Three new basic terms herein proposed are **"straighth"** (straightness), **"coolth"** (coolness), and **"goodth"** (goodness). They are exactly similar to warmth and illth, respectively, both good words of the lexicographer, and likewise are comparable to fulth, health, width, and many others.

The proposed basic term, "temper," for temperature is not new and is a shorter and simpler word having essentially the same meanings.

The proposed new basic term, **"rugaplane"** is a combination of the Latin *ruga*, a wrinkle, and *planus*, a plane (plain). The question as to whether it should be spelled ruga*plane* or ruga*plain* is open to argument because both the final members mean flat or level. The spelling, *plane*, seems preferable because that form is commonly used in English to denote a smooth or flat surface, and also because it does not suggest either homely or clear (evident).

Less happily composited is the proposed new term, **"ceptisist,"** meaning the condition of being susceptible or resistant. "Cept," in susceptible, comes from the Latin *suscipere* (*susceptus*), to be capable of taking, and "sist" in resistant from the Latin *sistere*, to stand fast. "Midceptisist" is the median condition between susceptibility and resistance. **"Ceptimmune"** is self-explaining.

AGRONOMIC AFFAIRS

SPECIAL COMMITTEES

President McCall has named the two following special committees to serve during 1928.

FERTILIZER DISTRIBUTING MACHINERY

Emil Truog, *Chairman* J. R. Fain F. E. Bear
S. B. Haskell

CORN BORER INVESTIGATIONS

L. E. Call, *Chairman* W. L. Burlison J. F. Cox
R. M. Salter F. D. Richey

RESOLUTION ON DEATH OF DEAN T. F. HUNT

While enroute from Honolulu where he had been in attendance, with Mrs. Hunt, upon the Pan Pacific Conference on Education, Dean Thomas Forsythe Hunt passed away on April 27, 1927. Dean Hunt was a charter member of the American Society of Agronomy and did much in its earlier years to guide aright its policies. Dean Hunt has served the cause of agriculture in five of our own states as well as several European countries, but his influence was world-wide.

In respect to his work and memory the following resolution was presented and adopted at the twentieth annual meeting of the American Society of Agronomy held at Chicago November 17 and 18, 1927.

"WHEREAS, in the recent death of Dean Thomas Forsythe Hunt, the American Society of Agronomy and agriculture in general has suffered the loss of one who as a pioneer teacher and investigator did much to advance the science of agronomy and made many valuable contributions to agricultural science, therefore,

"*Be it Resolved*, That the American Society of Agronomy, at this its twentieth annual meeting, hereby expresses its high appreciation of his work in connection with both teaching and research, and of his many fine personal qualities, and helpful influence upon his colleagues and students and

"*Be it Further Resolved*, That expression be given on this occasion to our deep sense of personal and professional loss in the passing of Dean Hunt."

NEWS ITEMS

F. J. SIEVERS, Professor of Soils and Soil Physicist at Washington State College, has been appointed Director of the Massachusetts Agricultural Experiment Station, effective February 1, to succeed Dr. S. B. Haskell who resigned to engage in commercial work.

W. W. WEIR, Associate Soil Technician, Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, has resigned to accept a position with the Chilean Nitrate of Soda Educational Bureau.

GEORGE A. OLSON, Agricultural Director of the Gypsum Industries, Chicago, Illinois, has resigned, effective February 1.

LARS G. ROMELL of the Swedish Forest Experiment Station at Stockholm has been appointed to the Charles Lathrop Pack Research Professorship in Forest Soils at Cornell University, effective April 1.

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SYMPOSIUM ON "COTTON"

Leader: M. J. FUNCHESS, Alabama Polytechnic Institute.

1. The Fruiting Habits of the Cotton Plant. T. S. Buie, Clemson College, South Carolina.
2. The Use of Fertilizers for Cotton. D. J. Burleson, Arkansas Agricultural Experiment Station.
3. The Effect of Spacing on the Yield of Cotton. C. A. Mooers, Tennessee Agricultural Experiment Station.
4. Some Economics of Cotton Production in the Southeastern States. F. W. Gist, Auburn, Alabama.
5. Cotton Production Methods in the Southwest. A. B. Conner, Texas Agricultural Experiment Station.

1. THE FRUITING HABITS OF THE COTTON PLANT[1]

T. S. BUIE[2]

Flowering in the cotton plant under the conditions prevailing in the Piedmont section of South Carolina begins some 8 to 11 weeks after planting and continues, unless stopped by insect attacks or cessation of plant growth, until frost. A fruit bud, or "square" as it is called, is normally borne at each node of each fruiting branch and is usually discernable some three to four weeks before the flower opens. This interval is known as the square period. The fruit buds are borne in regular succession, the first flowers to open being low on the plant and near the main stem, the next farther out on the branches or higher on the plant, etc., the succession being both centrifugal and acropetal (3).[3]

[1]Paper read as part of the symposium on "Cotton" at the meeting of the Society held in Chicago, Ill., Nov. 17, 1927. Contribution from the Department of Agronomy, South Carolina Agricultural Experiment Station, Clemson College, S. C.

[2]Agronomist

[3]Reference by number is to "Literature Cited," p. 201.

Fertilization occurs within a few hours after the flower opens, and in from one to two days the flower drops leaving the small boll. Many more bolls are produced than the plant is able to mature, the surplus being shed usually within 8 to 10 days after flowering. As many as 50% of the immature bolls may shed under normal conditions. This percentage is of course variable and depends upon many factors the most important of which is probably soil moisture.

The young boll grows rapidly for three to four weeks in which time full size is reached. This period is followed by a maturing or ripening process which requires from three to four weeks additional. Thus, it is seen that from six to eight weeks elapse between flowering and the opening of the mature boll. This is known as the boll maturation period, or simply as the boll period.

The greater part of the published research on the fruiting of the cotton plant is from work conducted in Egypt, the West Indies, and southwestern United States where the prevailing conditions are not comparable to those of the southeastern part of this country. In many cases the species used was some other than *Gossypium hirsutum*, so that for this additional reason the results secured are not thoroughly applicable to the eastern part of the cotton belt.

The work of Ewing (5) in Mississippi represents the greatest contribution to the knowledge of the fruiting habits of the cotton plant as grown in the southeast. This work was done some 15 years ago, prior to the advent of the boll weevil (*Anthonomus grandis*, Boh), and therefore, is not thoroughly applicable to present day conditions.

The production of an early crop of cotton was not considered of special importance until the arrival of the boll weevil, the depredations of this insect being very great especially late in the season. The production of cotton under boll weevil conditions has become largely a race between the farmer and the weevil. This necessitates the production of an early crop but without the sacrifice of desirable characters of quality meanwhile.

In 1923 the Agronomy Division of the South Carolina Experiment Station undertook a series of experiments to study the factors concerned with the production of fruit in the cotton plant, particular attention being paid to the study of those environmental factors concerned with earliness.

Briefly, the method employed consisted of daily observations on a large number of plants similarly treated. All open flowers were tagged and a record kept of the fate of each boll developing therefrom.

These studies have been continued since that time, and much interesting data have been accumulated. It is the purpose of this paper to present very briefly a summary of some of the more important phases of this work. Credit is due to all members of the Agronomy Research Staff who since 1923 have contributed to this investigation.

The time of the production of the initial flower is variable, being as Balls (2) has stated, the ultimate result of a long series of interacting factors, both morphological and physiological. It would appear that the same reasoning would apply to the production of any subsequent flower, so that the final daily flowering curve would be dependent upon the interaction of a number of factors, each subject to individual fluctuation and variation. The daily flowering curve, then, might be expected to fluctuate greatly, and this is indeed the case.

When the time interval is made greater, that is to say when the number of flowers are plotted by weekly intervals, the curve becomes much smoother and more regular. The curve rises somewhat slowly at first, then more rapidly, reaching the maximum about five weeks after fruiting commences (six weeks in 1925) and then falls more or less rapidly for about three weeks.

The data presented in Table 1, which have been previously reported by the author (4), illustrate this point quite well.

TABLE 1.—*Number of blooms appearing by weeks on 1,000 cotton plants at Clemson College, 1923-1925.*

	1923	1924	1925
1st week	198	108	150
2nd week	2,714	1,012	2,178
3rd week	4,770	1,458	3,950
4th week	8,940	5,022	9,148
5th week	9,858	11,324	9,064
6th week	5,434	8,224	10,918
7th week	2,760	4,440	3,124
8th week	———	1,328	164
Total	34,674	32,916	38,686

These data are particularly interesting when considered in connection with those presented in Table 2. In the latter table are given the percentages of these same flowers which matured bolls of cotton.

It will be noted from a study of these two tables that, although fruiting is not so rapid for the first three weeks, the probabilities of these early flowers producing open bolls is much greater than that of those produced late in the season. The chance is about equal for flowers appearing during the first three weeks, but after that

TABLE 2.—*Summary of percentage of blooms maturing bolls by weekly periods throughout season, Clemson College, 1923–1925.*

Week of fruiting	1923	1924	1925	Average
First	82.8	79.6	97.3	86.6
Second	83.0	85.0	98.6	88.9
Third	79.6	89.9	92.9	87.5
Fourth	47.5	89.5	76.4	71.1
Fifth	50.5	64.3	23.2	46.0
Sixth	35.0	30.3	4.6	23.3
Seventh	14.8	16.0	6.2	12.3
Eighth	——	18.5	6.1	12.3
Average	51.2	53.1	40.7	48.3

time there is a very rapid decrease in the possibility of a bloom producing an open boll. Expressed differently, a few flowers early in the season are worth many late ones. This illustrates the extreme necessity of following those practices which will result in the production of a large amount of fruit early in the season, but without the sacrifice of any other more desirable characters such as quality or length of staple. It is realized, of course, that greatly increasing the number of early season flowers would result in heavier shedding at this time, but the climatic conditions usually prevailing early in the season are less conducive to shedding and the early production of fruit would also minimize boll weevil losses.

It has been observed that varieties which produce a large percentage of their fruit early in the season produce much less late fruit, and vice versa. This is clearly illustrated by the data given in Table 3. The fruiting period for each year has been divided into three intervals of approximately three, two, and three weeks, respectively. The figures represent the percentage of total flowers produced during each of these three periods.

TABLE 3.—*Per cent total flowering by periods, three year average, Clemson College, 1923–1925.*

Variety	1 to 3 weeks	4 to 5 weeks	6 to 8 weeks
Cleveland	16.5	57.8	25.7
Trice	30.2	57.5	12.3
Acala	30.3	53.8	15.9
Dixie Triumph	15.5	53.5	31.0
Salsbury	14.3	50.2	35.5
Mexican Big Boll	26.0	49.0	25.0
Webber 49	16.9	54.8	28.3
Lightning Express	27.6	50.4	22.0

The time at which the seed are planted is an important determiner of the time and rate of early fruiting in the cotton plant. It has been stated above that flowering normally begins at Clemson College some 8 to 11 weeks after planting. This depends largely upon the

time of planting and the weather conditions prevailing for the first few weeks thereafter. Plants developing early in the season require longer to produce the initial flower than do those from later plantings, but when fruiting once commences it is much more rapid in the older plants. This is illustrated by the data presented in Table 4 which gives the number of flowers produced per 100 plants of each treatment by weeks during the season of 1924.

TABLE 4.—*Production of flowers by weeks, 100 plants each planting date, Clemson College, 1924.*

Date of planting	July 18	July 25	Aug. 1	Aug. 8	Aug. 15	Aug. 22	Aug. 29	Sept. 5	Total
Greenhouse[a]	75	130	105	405	800	525	335	80	2,455
April 24	30	75	50	330	590	475	330	110	1,990
May 7.... ...	—	30	50	295	660	455	320	155	1,965
May 21.. ...	—	—	5	145	410	375	270	210	1,415
June 4....	—	—	—	70	220	330	255	350	1,225
June 18.......	—	—	—	—	—	25	130	175	330

[a]Transplanted last of April.

From a study of this table it will be noted that delaying the planting for two weeks had in almost every case the effect of delaying the production of the first flower only approximately one week. It will also be noted that the early plantings had produced by midseason a much larger number of flowers which had a greater possibility of developing into open bolls than did those borne later. Ballard and Simpson (1) have also observed that the later plantings develop to the flowering stage quicker but produce fewer flowers during the first part of the fruiting period than do plants from early plantings.

The effect of spacing on the production of fruit early in the season is also important. Generally speaking, crowding the plants somewhat in the row has a tendency to reduce to a minimum the production of vegetative parts and thereby hastens fruiting.

On the plats selected for study at Clemson College it has been noted repeatedly that close spacing has resulted in the production of more fruit early in the season, although not necessarily more total bolls. The early flowers are the important ones, however, and relatively close spacing is to be encouraged for this reason.

Table 5 gives the number of bolls per acre at intervals of two weeks on plants variously spaced in 1924. It is interesting to note that the closely spaced plants began fruiting much earlier than did those which had an abundance of room for vegetative growth.

The size of boll and percentage of lint have been found to be but slightly affected, if at all, by variations in the spacing of the plants.

TABLE 5.—*Bolls per acre, spacing test, Clemson College, 1924.*

		Spacing distances		
Date	Unthinned	8 inches	16 inches	24 inches
Aug. 1	46,049	17,405	12,189	13,096
Aug. 15	176,319	118,460	106,852	90,858
Aug. 29	162,639	117,500	117,295	111,909
Sept. 12	119,771	104,628	100,043	94,097

The boll period was also found to vary but very little with the different spacings. Of the distances used at Clemson College, one plant every 8 inches has given the earliest as well as the highest total yield over a period of years.

A very interesting fact in connection with the fruiting of the cotton plant was brought out by a minor study undertaken in 1924. On a group of plants all blooms were removed daily as they appeared and on a corresponding group, otherwise similarly treated, the flowers were allowed to remain on the plants and develop normally. It will be noted from Table 6 that for the first three weeks the number of flowers was almost identical, but after this time there was a great stimulation in the fruiting activity. This period of three weeks agrees very closely with the "square" period, or time required for the development of the fruit bud to the flowering stage which is approximately three to four weeks. Thus, it is seen that the removal of all flowers had a direct stimulating effect on the plant, causing it to produce more reproductive growth almost immediately but this was not noted until the lapse of some three weeks when the resulting "squares" bloomed

TABLE 6.—*Effect upon subsequent flowering of removal of all blossoms daily, 100 plants each treatment.*

	July 23	July 30	Aug. 6	Aug. 13	Aug. 20	Aug. 27	Sept. 3	Sept. 10	Sept. 17	Total
Check	58	200	319	469	263	73	5	---	---	1,387
Flowers removed	72	182	337	523	456	193	165	122	65	2,115

The fertilizer used in the production of cotton has a marked effect upon the rate of fruiting. Ewing (5) showed that the fertility of the soil greatly influenced the rate of fruiting, and the work of the South Carolina Experiment Station also shows that the elements which are used in the fertilizer have a marked effect upon both the first flower and the rate of production of subsequent ones.

The effect of phosphorus in hastening the maturity of a crop has long been known, in fact this is one of the principal functions of the element. It is to be expected, therefore, that the use of large amounts of phosphatic fertilizers would hasten the production and development of bolls.

A very comprehensive fertilizer test is being conducted on the Pee Dee Branch Station at Florence, S. C., where numerous plats have received similar treatment (with only slight modification in 1920) since 1914. The cropping system employed is a three-year rotation consisting of cotton the first year, corn with a companion crop of peas the second year, and oats followed by peas cut for hay the third year. When the experiment was begun the soil was in a very fertile condition which has been at least maintained if not materially increased. As a result, the need for nitrogen is not nearly so marked as on many other Coastal Plain soils of the state.

It was believed that these plats offered a splendid opportunity to study the effect of the several fertilizer elements on the fruiting activities of the cotton plant. Accordingly, plans were made in 1925 to study the rate of fruiting on the plants of a number of selected plats Warner (6) has reported in a previous paper the effect of the various fertilizer treatments on the rate of fruiting in 1925, and an additional year's data are added and presented in Table 7.

TABLE 7.—*Effect of various fertilizer treatments on earliness and yield of cotton, two years' results at Pee Dee Station, Florence, S. C.*

Fertilizer[a]	Flowers produced first 5 weeks			Percentage yield at first pick		
	1925	1926	Average	1925	1926	Average
None	1,746	988	1,367	48.9	93.3	71.1
0-4-4	1,620	1,320	1,470	33.9	79.2	56.6
2-4-4	2,009	1,682	1,846	42.2	86.3	64.3
6-4-4	2,554	1,698	2,126	47.9	91.2	69.6
8-4-4	2,378	2,132	2,255	47.1	92.3	69.7
12-4-4	2,800	1,772	2,286	50.3	89.5	69.9
8-0-4	2,534	2,058	2,296	52.3	84.8	68.6
8-3-4	2,465	2,304	2,385	47.6	89.6	68.6
8-4-4	2,378	2,132	2,255	47.1	92.3	69.7
8-6-4	2,977	2,090	2,534	46.1	92.8	69.5
8-10-4	2,623	2,576	2,600	38.2	91.0	64.6
8-4-0	2,568	1,936	2,252	52.3	94.1	73.2
8-4-2	3,220	2,122	2,671	48.3	92.1	70.2
8-4-4	2,378	2,132	2,255	47.1	92.3	69.7
8-4-6	2,750	2,258	2,504	44.1	89.7	66.9

[a]Applications made at rate of 1,000 pounds per acre.

It is very interesting to note that every rate of increase of phosphorus has resulted in an increase in the number of flowers produced in the first five weeks of fruiting. The rate of increase, however, was not great when the percentage of phosphoric acid was increased above 6%. The percentage of total yield obtained at first picking was also greater with increased applications of phosphorus, but again the rate of increase was not rapid when more than 6% of phosphoric acid was used.

It might be expected that at least a part of this increased earliness is due to a more rapid development of the boll, but apparently this is not the case as the boll period for the two years shows no significant change from the application of phosphorus. In other words, the principal effect of phosphorus in inducing earliness appears to be in securing the earlier production of fruit rather than the more rapid development and maturation of the boll. Boll period studies conducted on the same plats for the two years indicate that the fertilizer treatment has but little effect on the time required for the boll development. It should be mentioned, however, that neither 1925 nor 1926 were altogether normal seasons so that differences may have been masked by other factors. It is hoped that the 1927 data may be more conclusive on this point.

Increasing the amount of nitrogen in the formula did not have nearly so great an effect as increasing the phosphorus. This is to be expected on this particular soil, although the same would not hold for all soil types found in the state. In fact, other similarly conducted experiments on lighter soil types have shown a remarkable effect of nitrogen in inducing early fruiting. The addition of ammonia to the fertilizer formula has had the effect of slightly increasing the number of flowers produced by midseason, however.

The addition of potash to the formula resulted in the production of more blooms during the first five weeks of fruiting, although this increase was not entirely consistent. The greatest increase came from the use of 2% potash which in a 1,000-pound application provided 20 pounds of K_2O. The addition of potash to the formula also slightly delayed the crop, as indicated by the percentage of total yield obtained at the first picking. These differences are hardly significant, however.

SUMMARY

1. The production of an early crop of bolls is of extreme importance, especially under boll weevil conditions.

2. Early season flowers have a much better chance to develop into open bolls than do those appearing late in the season.

3. The peak of flowering is reached under conditions prevailing at Clemson College in 1923 to 1925 during the fifth to sixth week of fruiting.

4. Varieties which produce a large percentage of their fruit early in the season bear but few flowers late in the season, and vice versa.

5. Early plantings produce plants which require a slightly longer period to begin fruiting but produce many more flowers early in the season.

6. Close spacing of plants induces early fruiting.

7. Removal of all flowers as they appear stimulates the plant to greater reproductive activity.

8. Phosphorus has the effect of hastening the fruiting of the cotton plant.

9. Nitrogen on a fertile soil unresponsive to this element has but little effect in stimulating the production of early fruit. On infertile soils the reverse is the case.

10. Potash, under the conditions prevailing, has increased the number of flowers borne prior to midseason, but has slightly decreased the percentage of total yield obtained at first picking.

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2. THE USE OF FERTILIZERS FOR COTTON[1]

D. J. BURLESON[2]

More than 97% of the total cotton acreage in the United States is planted in the 10 states of North Carolina, South Carolina, Georgia, Alabama, Mississippi, Tennessee, Arkansas, Louisiana, Oklahoma, and Texas. In 1926, $78,682,000 was spent for fertilizers for the cotton crop in these states, an increase of about 5% above the amount spent in 1925 and of about 32% above the amount spent in 1924.

The use of fertilizers is by no means uniform throughout the cotton belt. With regard to the amounts of fertilizers used the 10 cotton states fall into three groups, *viz.*, the eastern group composed of North Carolina, South Carolina, Georgia, and Alabama; the central group composed of Mississippi, Tennessee, Arkansas, and Louisiana; and the western group composed of Texas and Oklahoma. In the eastern group of states 94% of the cotton acreage was fertilized in 1926, in the central group 43.5%, and in the western group 5.6%.

The acreage fertilized in the eastern group in 1926 received on the average 302 pounds of fertilizer per acre at a cost of $4.67, the central group 204 pounds per acre at a cost of $3.87, and the western group 184 pounds per acre at a cost of $3.42.

The eastern group of states in 1926 planted 25.9% of the cotton acreage in the United States and used 71% of the total amount of fertilizer applied to cotton, the central group planted 22.3% of the total acreage and used 23% of the total amount of fertilizer, while the western group planted 49.3% of the total acreage and used 6% of the total amount of fertilizer.

Table 1 gives a summary of the fertilizer situation in the 10 cotton states in 1926.

If the total amount of money spent in each group of states for cotton fertilizers in 1926 is divided by the number of acres in the group, it is found that there is an average fertilizer charge of $4.40 against each acre in the eastern group, $1.68 in the central group, and $0.19 in the western group.

Experiment stations and the experience of farmers have proved that fertilizers for cotton, as ordinarily applied, are profitable. But

[1]Paper read as part of the symposium on "Cotton" at the meeting of the Society held in Chicago, Ill., Nov. 17, 1927. Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Ark.

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TABLE I.—*Percentage of cotton acreage fertilized by states, amount of fertilizer used, and value in 1926.*

State	Acreage fertilized %	Pounds fertilizer used per acre	Value per acre	Total value, 000 omitted
North Carolina	95	440	$6.62	$13,211
South Carolina	94	325	4.74	12,441
Georgia	96	257	4.00	15,454
Alabama	91	255	4.23	14,587
Eastern group	94.2	302	4.67	55,693
Mississippi	48	222	4.16	7,555
Louisiana	42	190	3.67	3,047
Arkansas	40	185	3.55	5,353
Tennessee	50	220	3.98	2,374
Central group	43.5	204	3.87	18,328
Texas	7	185	3.44	4,563
Oklahoma	0.7	175	2.72	98
Western group	5.6	184	3.42	4,661
Total				78,682

it has been just as thoroughly proved that a great deal more profit is obtained from applications of better grade and in larger amounts than those ordinarily used.

RELATIVE RESPONSE TO PHOSPHORUS, NITROGEN, AND POTASH

The relative amounts of the three fertilizer elements in a fertilizer mixture are strong factors in determining the efficiency and value of fertilizers for cotton. Probably more work has been done by experiment stations to determine the most efficient proportion of plant-food constituents than on any other problem affecting cotton fertilizers.

The importance of correct proportioning of the fertilizer elements is well illustrated by the results of experiments by the North Carolina Station with equal amounts of two different grades of fertilizers, 9-3-3 and 6-6-3. On five soil types it was shown that the 6-6-3 grade produced sufficient increases in yield over that produced by the same amount of the 9-3-3 grade to pay for the whole of the 6-6-3 mixture with additional profits as follows:

Dunbar fine sandy loam soil—$6.65
Portsmouth sandy loam soil—$4.98
Wickham fine sandy loam soil—$17.43

On Rustom sandy loam the better grade produced 76 pounds more of seed cotton per acre than the poorer grade and on Georgeville silt loam 70 pounds.

TABLE 2.—*Relative response of cotton to phosphorus, nitrogen, and potash in a complete fertilizer on five soil types in Alabama.*

Fertilizer	Basis of value	Norfolk South	Black Belt	Piedmont	Appalachian Plateau	Decatur
240 pounds superphosphate (acid phosphate)	Seed cotton per acre	89	76	87	114	109
	Per dollar invested	$2.97	$2.53	$2.90	$3.80	$3.63
200 pounds cottonseed meal	Seed cotton per acre	148	85	120	142	173
	Per dollar invested	$1.97	$1.13	$1.60	$1.89	$2.31
100 pounds nitrate of soda	Seed cotton per acre	188	82	164	147	239
	Per dollar invested	$4.10	$1.79	$3.57	$3.21	$5.21
100 pounds kainit	Seed cotton per acre	73	56	21	41	65
	Per dollar invested	$5.84	$4.48	$1.68	$3.28	$5.20

The data in Table 2 indicate that in Alabama on the soil types included in the experiments nitrogen in nitrate of soda is more effective in increasing yields than either phosphorus or potash when the rate of application is approximately 450 pounds per acre of a 9-3.5-3 grade. In some cases the return per dollar invested in nitrate of soda was not as great as for the other elements, because nitrogen is so much more expensive than either phosphorus or potash. However, the profit per acre from nitrogen is greater than from either phosphorus or potash on all five of the soil types.

In Table 2 the increase in yield for a given element was obtained by comparing the yield from a complete fertilizer with the yield from a mixture in which that element was not included.

In Table 3 is shown the effect of using various amounts of phosphoric acid in a complete fertilizer. In all the tests recorded in this table the rate of application is high, therefore, there is wide difference between the successive amounts of phosphoric acid applied. In South Carolina an application of 1,000 pounds per acre of a mixture containing 4% nitrogen and 4% potash with varying amounts of phosphoric acid was applied to Orangeburg fine sandy loam and Norfolk sandy loam. On the Orangeburg soil 4% phosphoric acid increased the yield of seed cotton 230 pounds over the yield from the mixture containing no phosphate. The mixture containing 8% increased the yield 45 pounds more than the 4% mixture, while the mixture containing 16% phosphoric acid produced 30 pounds more of seed cotton than did the 8% mixture. On the Norfolk sandy

TABLE 3.—*Effect on yield of seed cotton of varying amounts of phosphorus in a complete fertilizer in South Carolina.*

Application per acre		Seed cotton per acre	
Rate in pounds	Kind	Yield in pounds	Successive increase in pounds
		Orangeburg fine sandy loam, 6 years	
1,000	0-4-4	1,650	—
1,000	4-4-4	1,880	230
1,000	8-4-4	1,925	45
1,000	16-4-4	1,955	30
		Norfolk sandy loam, 3 years	
1,000	0-4-4	551	—
1,000	2-4-4	793	242
1,000	4-4-4	828	35
1,000	6-4-4	954	126
1,000	8-4-4	863	—91
		Ruston sandy loam, 3 years	
600	0-4-3	1,103	—
600	2-4-3	1,147	44
600	4-4-3	1,076	—71
600	6-4-3	1,191	115
600	8-4-3	1,174	—17
600	10 4 3	1,198	24

loam the successive increases in yield of seed cotton for each increase in percentage of phosphoric acid were as follows: The first 2% produced 242 pounds; the second 2%, 35 pounds; the third 2%, 126 pounds; and the fourth 2%, 35 pounds, or 91 pounds less than 6% produced.

On Ruston sandy loam in South Carolina 600 pounds of a mixture containing 4% nitrogen and 3% potash with phosphoric acid varying from none to 10% were applied to cotton. The successive increases in phosphoric acid content were by 2%. The first 2% showed an increase of 44 pounds of seed cotton; the second 2% showed a yield 71 pounds less than the first 2%; the third 2%, 115 pounds increase; the fourth 2%, a loss of 17 pounds; and the fifth 2%, 24 pounds increase.

The results recorded in Table 4 indicate that when a fairly heavy application of a mixture containing 8% phosphoric acid and 3% to 4% potash is applied to cotton on Ruston sandy loam and Norfolk sandy loam in South Carolina the yield is consistently increased as the percentage of nitrogen is increased up to about 6%. With an application of 600 pounds of fertilizer per acre (phosphoric acid 8% and potash 3% to 4%) on Ruston sandy loam and 1,000 pounds on Norfolk sandy loam, it was highly profitable for the mixture to carry as much as 6% nitrogen. On Ruston sandy loam 600 pounds per acre of 8-6-3 mixture produced 127 pounds more seed cotton than 600 pounds of 8-4-3. At 7 cents per pound for seed cotton

TABLE 4.—*Effect on yield of seed cotton of varying amounts of nitrogen in a complete fertilizer in rotation in South Carolina.*

Application per acre		Seed cotton per acre	
Rate in pounds	Kind	Yield in pounds	Successive increase in pounds
	Ruston sandy loam, 3 years		
600	8-0-3	725	
600	8-2-3	1,008	283
600	8-4-3	1,174	166
600	8-6-3	1,301	127
600	8-8-3	1,373	72
600	8-10-3	1,427	54
	Norfolk sandy loam, 3 years		
1,000	8-0-4	344	
1,000	8-2-4	573	229
1,000	8-4-3	863	290
1,000	8-6-3	992	129
1,000	8-8-3	1,043	51
	Orangeburg fine sandy loam, 6 years		
1,000	8-0-4	1,675	
1,000	8-2-4	1,846	171
1,000	8-4-4	1,925	79
1,000	8-8-4	1,916	--9

and $60.00 per ton for nitrate of soda this amount of seed cotton would pay for the difference in nitrogen and leave a balance of $6.49. On the Norfolk sandy loam where 1,000 pounds of fertilizer per acre was applied the mixture carrying 6% nitrogen produced 129 pounds more seed cotton per acre than that carrying 4%. At the above prices this increase would pay for the increased nitrogen and leave a balance of $6.03. On the Orangeburg fine sandy loam the results indicate that it was not profitable to increase the nitrogen content above 4% when 1,000 pounds of fertilizer per acre were applied.

Table 5 shows the results of six years' work with complete fertilizers containing 8% phosphoric acid, 4% nitrogen, and varying

TABLE 5.—*Effect on yield of seed cotton of varying amounts of potash in a complete fertilizer in South Carolina.*

Application per acre		Seed cotton per acre	
Rate in pounds	Kind	Yield in pounds	Successive increase in pounds
	Rotation with corn and peas and oats followed by peas		
1,000	8-4-0	1,776	
1,000	8-4-2	1,927	151
1,000	8-4-4	1,925	—2
1,000	8-4-8	1,809	—116
	Cotton continuous		
1,000	8-4-0	1,522	
1,000	8-4-2	1,687	165
1,000	8-4-4	1,877	190
1,000	8-4-8	1,752	—125

amounts of potash on Orangeburg fine sandy loam, including cotton continuous and cotton in a three years' rotation with corn and peas and oats followed by peas. When 1,000 pounds of fertilizer per acre were applied it was found profitable for the mixture to carry at least 4% potash, but in the rotation 4% potash produced practically the same yield as 2%. The latter was highly profitable, producing 151 pounds of seed cotton more than the mixture without potash.

The Alabama Station has been carrying on tests in which the effect of an application of 200 pounds superphosphate (acid phosphate), 100 pounds nitrate of soda, and 25 pounds of muriate of potash per acre is compared with the effect of double this amount of each material, and also with a double application of all except one material. This work was done on Norfolk, Greenville, Dekalb, and Decatur soils.

On these four Alabama soils it was found that doubling all three of the fertilizer materials gave greater yields of seed cotton than any other combination. Doubling all three materials produced increases over doubling all except superphosphate (acid phosphate) by amounts varying from 55 pounds of seed cotton per acre on Decatur to 100 pounds on Dekalb. Doubling all three was better than doubling all except nitrate of soda by amounts varying from 129 pounds of seed cotton per acre on Decatur to 157 pounds on Dekalb. Doubling all three gave increases over doubling all except potash by amounts varying from 33 pounds of seed cotton per acre on Greenville to 82 pounds on Norfolk.

EFFECT OF DIFFERENT AMOUNTS OF COMPLETE FERTILIZER ON YIELD AND PROFIT

As shown in Table, 6 the North Carolina Station made applications of different amounts of a fertilizer mixture containing 7% phosphoric acid, 3% nitrogen, and 2.5% potash to cotton in the Coastal Plain and in the Piedmont. In both the Coastal Plain and in the Piedmont there is a consistent gain in the yield of seed cotton as the quantity of fertilizer is increased by 200-pound increments from 200 to 1,000 pounds per acre. Also, on both soil divisions the greatest profit per acre was found where 1,000 pounds of fertilizer were applied per acre. In the Coastal Plain the profit per acre above the cost of fertilizer varied from $9.48 with an application of 200 pounds per acre to $54.75 with an application of 1,000 pounds, while in the Piedmont the variation of profit per acre was from $25.90 for the 200-pound rate of application to $58.46 with the 1,000-pound application. However, the difference in return per

TABLE 6.—*Effect of different quantities of complete fertilizer upon yield and profit of seed cotton in North Carolina.*

Application in pounds per acre of 7–3–2½ fertilizer	Increase per acre in yield of seed cotton, pounds[a]	Value of increase per acre at 7 cents per pound	Cost of fertilizer per acre	Profit per acre over cost of fertilizer	Net returns for $1.00 invested in fertilizer
Coastal Plain, Edgecombe, seven years					
200	179	$12.53	$3.05	$9.48	$3.11
400	348	24.36	6.10	18.26	2.99
600	667	46.69	9.15	37.54	4.10
800	890	62.30	12.20	50.10	4.11
1,000	1,000	70.00	15.25	54.75	3.59
Piedmont, Iredell, five years					
200	402	$28.14	$3.05	$25.90	$8.22
400	707	49.49	6.10	43.39	7.11
600	858	60.06	9.15	50.91	5.56
800	939	65.73	12.30	53.53	4.39
1,000	1,053	73.71	15.25	58.46	3.83

[a]These increases are for yields above plats receiving no fertilizer.

acre between the 800-pound and the 1,000-pound applications is not sufficiently great in the Coastal Plain to justify an application of 1,000 pounds in farm practice. The authors reporting these experiments state that the results indicate that the most economical application is 800 pounds per acre.

TABLE 7.—*Effect of different amounts of 8–4–4 fertilizer on yield of seed cotton in North and South Carolina.*

Rate of fertilizer application per acre in pounds	Yields seed cotton per acre in pounds	Gain of seed cotton in pounds per acre: Over check	Gain of seed cotton in pounds per acre: Successive
North Carolina, Wickham fine sandy loam			
None	342	—	—
300	868	526	—
500	1,134	792	266
700	1,234	882	90
900	1,422	1,080	198
South Carolina, Norfolk sandy loam			
None	297	—	—
400	540	243	—
600	678	381	138
800	721	424	43
1,000	773	476	52
1,200	792	495	19
1,400	834	537	42
1,600	892	595	—

The results of experiments in North Carolina on Wickham fine sandy loam and in South Carolina on Norfolk sandy loam, as reported in Table 7, show that every 200-pound per acre increase

in the rate of application of a fertilizer of 8-4-4 grade produced an increase in the yield of cotton. However, in both cases there was a sharp falling off in the increase of yield from successive 200-pound increments after passing the 600-pound rate of fertilizer application. In both cases the results indicate that about 600 pounds per acre is the most economical rate of application.

TABLE 8.—*Effect of different amounts of complete fertilizer on yield of seed cotton on four soil types in Alabama.*

Amount and kind of fertilizer per acre[a]	Yield of seed cotton in pounds per acre Norfolk	Greenville	Dekalb	Decatur
No fertilizer	378	496	404	511
P N K	724	829	783	797
2 (P N K)	937	1,070	1,048	990
3 (P N K)	997	1,181	1,188	1,097

[a]P = 200 pounds superhposphate (acid phosphate), N = 100 pounds nitrate of soda, K = 25 pounds muriate of potash.

The Alabama Station has tested the effect of using 200 pounds per acre of superphosphate (acid phosphate), 100 pounds of nitrate of soda, and 25 pounds of muriate of potash as compared with double and treble these amounts. The results are shown in Table 8. These tests were made on four soil series, namely, Norfolk, Greenville, Dekalb, and Decatur. The single application was about equivalent to 400 pounds of 9-4-3 fertilizer per acre. In each case it was highly profitable to use the double application as compared with the single application, producing increases over the single application of enough seed cotton to be worth from $13.51 to $18.55, valuing seed cotton at 7 cents per pound. The profit from the use of the double application over that from the single application would average more than $8.00 per acre.

ECONOMICAL PROPORTIONS AND AMOUNTS OF FERTILIZER MIXTURES

A study of the data obtained from experiments with fertilizers for cotton in the various states indicates that on most soils the most economical amounts to apply per acre of each fertilizer constituent are about as follows: Phosphoric acid from 40 to 60 pounds, nitrogen from 25 to 40 pounds, and potash from 15 to 30 pounds. The Piedmont soils, hill sections in general, give better response to phosphoric acid than the Coastal Plain soils, while the reverse is true with potash. On all soil types nitrogen is highly effective and larger amounts of nitrogen would be recommended if it were not so much more expensive than phosphoric acid and potash. On the heavy lowland soils phosphoric acid is least effective.

In general, it may be said that an economical fertilizer application for the various sections would consist of about 600 pounds to the acre under good cultivation and that the analysis for the hill sections should be about 10-4-3, for the Coastal Plain soils about 7-5-4, while some of the heavier delta soils give most economical results with 200 to 300 pounds of nitrate of soda or equivalent amount of sulfate of ammonia or other quickly available source of nitrogen.

Of course, there are conditions which make it advisable to modify these applications. The growing of legume crops for soil improvement in rotation with cotton makes it advisable to apply less nitrogen. Also, where methods of cultivation are extensive rather than intensive less fertilizer should be applied. In the western part of the cotton belt where rainfall is low it is probable that the amount of fertilizer applied per acre should be lower than in the eastern part.

RELATIVE MERITS OF DIFFERENT SOURCES OF NITROGEN

That there is a great deal of difference in the efficiency of various sources of nitrogen as fertilizer for cotton has been proved by several experiment stations. In South Carolina experiments covering six years were conducted in which 1,000 pounds of 8-4-4 fertilizer were applied per acre, using various materials as the source of nitrogen. In these experiments the increases in yields of seed cotton for the various sources over the yields from an application of 1,000 pounds of 8-0-4 were as follows: Nitrate of soda, 152 pounds of seed cotton; sulfate of ammonia, 114 pounds; cyanamid, 80 pounds; and cottonseed meal, 25 pounds.

In Alabama, on unlimed land, where 200 pounds per acre of nitrate of soda, or its equivalent in sulfate of ammonia, were applied in a complete fertilizer, the increases for each source of nitrogen in yields per acre of lint cotton were 66.8 and 42.6 pounds, respectively.

When lime was applied the increases were 71 pounds of lint cotton from nitrate of soda and 67.6 pounds from sulfate of ammonia.

When the equivalent of 400 pounds per acre of nitrate of soda was applied on unlimed land the increase was 68.8 pounds for nitrate of soda and 22.7 pounds for sulfate of ammonia. The same amount of nitrogen on limed land gave an increase for nitrate of soda of 85.1 pounds and for sulfate of ammonia of 92.3 pounds.

With the application of lime, nitrate of soda and sulfate of ammonia were equally efficient, but without lime nitrate of soda was much more efficient, especially with the heavier applications.

3. THE EFFECT OF SPACING ON THE YIELD OF COTTON[1]

C. A. MOOERS[2]

PRELIMINARY CONSIDERATIONS

Since the advent of the boll weevil the spacing of cotton has received increased attention, because spacing influences earliness, closely spaced plants fruiting somewhat earlier than widely spaced. Precise comparison of data from different states on the spacing of cotton is made difficult by the lack of uniformity in the conduct of the experiments. For example, the width of row used has been from 3 to 5 feet. In the older experiments the closest spacing was frequently only 1 foot, the next spacing was 2 feet, and a third spacing of 3 feet completed the series. In the more recent studies 3-inch variations have been commonly used. Different varieties of cotton have been employed, but this factor is probably of no special bearing on the results. The assumption has been generally made, however, that soil and climatic conditions have a marked effect on the spacing which should be allowed; in short, that they are the factors of major importance.

In order to place the available data on a more readily comparable basis, the author has taken a 3½-foot row as the standard and has recalculated to that basis the spacings in experiments made with 3-foot and 4-foot rows. Data from rows wider than 4 feet were not included. In the interpretation of the data all yields were placed on a lint-cotton basis and the "best" spacing in a year's trial was determined by averaging two or more spacings which gave yields within the limits of experimental error. Occasionally, however, the high yield of the closest spacing, together with a consistent reduction in yield with increased spacing, was assumed to warrant the selection of the closest spacing as the "best." Also, in some instances, the irregularity of the plat yields would not allow the rules to be strictly followed, and a somewhat more liberal interpretation was made.

Plat yields of any year were considered the same within the limits of experimental error according to the following standards:

[1]Paper read as part of the symposium on "Cotton" at the meeting of the Society held in Chicago, Ill., Nov. 17, 1927. Contribution from Department of Agronomy, Tennessee Agricultural Experiment Station, Knoxville, Tenn.

[2]Director of Station and Head of Department.

Yield per acre in pounds	Variation allowed, %
600 or more	5
450–600	6
300–450	7
150–300	8
1–150	10

TABLE 1.—*Yields of lint cotton per acre from the Texas experiments on the spacing of cotton with "best" spacing on the basis of 3½-foot rows.*

Place	Year	One plant per hill		Two plants per hill	
		Yield	Best spacing	Yield	Best spacing
		Pounds	*Inches*	*Pounds*	*Inches*
Angleton	1917	315	13		
	1918	293	8		
	1919	162	12		
	1920	336	17		
	1921	101	14		
	1922	204	26		
	1923	66	6		
	1924	320	16		
	Average	225	14		
Beeville	1915	329	8	263	19
	1917	91	14	84	19
	1918	128	19	167	19
	1919	142	12	97	15
	1920	373	10	539	18
	1922	99	21	85	23
	1923	168	14	178	13
	1924	195	17		
	1925	260	15		
	Average	198	14	202	18
Chillicothe	1919	380	13		
	1920	392	21		
	1921	327	18		
	1922	145	21		
	1924	340	21		
	Average	317	19		
College Station	1914	298	10		
	1915	312	23	270	22
	1916	347	5	349	10
	1917	64	19	83	23
	1919	190	8	121	21
	Average	242	13	206	19
Lubbock	1913	157	12		
	1914	640	12		
	1915	351	10		
	1916	296	5		
	1917	138	6		
	1918	171	21		

TABLE 1.—*Continued.*

Place	Year	One plant per hill Yield	One plant per hill Best spacing	Two plants per hill Yield	Two plants per hill Best spacing
		Pounds	*Inches*	*Pounds*	*Inches*
Lubbock	1919	433	17		
	1920	166	17		
	1921	261	12		
	1922	254	20		
	1923	354	5		
	1924	142	18		
	Average	280	13		
Nacogdoches	1915	309	23	414	26
	1916	196	21	157	24
	1917	126	18	158	28
	1918	174	14	241	22
	1919	25	22	31	24
	1920	87	19		
	Average	153	20	200	25
Pecos	1916	275	14		
	1917	53	10		
	1919	239	12		
	Average	189	12		
Spur	1914	562	13		
	1915	322	12		
	1917	287	8		
	1919	376	18		
	1921	263	12		
	1922	178	12		
	1923	76	12		
	1924	165	12		
	Average	279	12		
Temple	1915	237	22	229	14
	1916	374	13	383	22
	1917	181	18	195	10
	1918	82	26	70	21
	1919	240	15	420	22
	1920	818	22	818	28
	1921	265	18		
	Average	314	19	353	20
Troup	1915	271	26	255	19
	1917	179	17	177	21
	1918	224	22	215	23
	Average	225	22	216	21
State Average		247	15	240	20

These allowances may seem large, but a study of the yields from replications will generally show even wider variations. Also, there is probably little difference in the final conclusions reached whether these or some other standards are used, provided a uniform procedure is followed throughout.

THE TEXAS DATA

Data from spacing experiments are available from nearly all of the cotton-growing states, but those from Texas (1)[3] are outstanding because of both the number and the completeness of the trials. In fact, there are reported in Bulletin 340 of the Texas Station the results of trials at 10 different places with an average of 6.6 years at a place, or nearly as many as are reported from all other states combined. In all the Texas experiments 3-foot rows were used, and, with a single exception, 3-inch intervals, beginning with 3 inches and

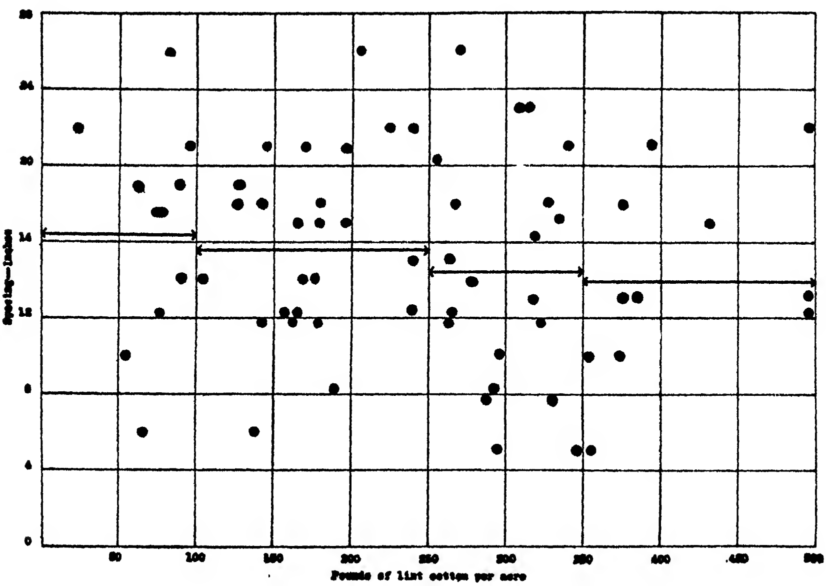

FIG. 1.

extending to 36 inches. At all places trials were made with one plant to the hill. In addition trials were made with two plants per hill at five different places, with an average duration of five years at a place.

EXPERIMENTS WITH ONE PLANT TO THE HILL

The best spacings with one plant per hill as interpreted by the author, and when converted to the basis of 3½-foot rows, are given in Table 1. The results show wide variations as to "best" spacing,

[3]See list of "References," p. 229.

as may readily be seen from Fig. 1, which shows the outcome for each year's trial at all of the 10 places. The extremes are 5 and 26 inches. It is of special interest, however, to note that wide annual variations are characteristic of the results at each of numerous places, and that the longer the period of the experiments the more is such an outcome in evidence. The outcome of the 12 years' experiments at Lubbock, for instance, is as follows:

Best spacing in inches	Number of years obtained
3–7	3
8–12	4
13–17	2
18–22	3

The extremes of "best" spacing during the 12 years were 5 and 21 inches, which are nearly as wide as the extremes for all places. It is evident, therefore, that even the 12-year period was insufficient to fix a definite best distance. Similar results were obtained both at Angleton, where in an eight-year period the extremes were 6 and 26 inches, or within an inch of the extremes of all places; and at Beeville, where in a nine-year period the extremes were 8 and 21 inches. If, however, the data be averaged for each place, more uniformity is evident. The averages are as follows:

Place	Years of trial	Average of "best" spacing in inches
Angleton	8	14
Beeville	9	14
Chillicothe	5	19
College Station	5	13
Lubbock	12	13
Nacogdoches	6	20
Pecos	3	12
Spur	8	12
Temple	7	19
Troup	3	22
Total number of years	66	Average per place 16

The extremes are 12 and 22 inches, and the general average is 16 inches. Obviously, however, it is unfair to place a 3-year trial, as at Troup, on a parity with a 12-year trial, as at Lubbock, and if equal weight is given to each of the 66 years the average "best" spacing is 15 inches.

ALLOWABLE VARIATION FROM "BEST" SPACING

The question arises as to the allowable variation from the "best" spacing. That is, to what extent, if any, can the distance be varied without appreciable decrease in yield. To answer the question, there are at least two methods of approach. One is to average the actual yields at every spacing from 3 to 36 inches. Unfortunately, there are numerous gaps in the records, that is, yields are missing to a greater or less extent in nearly every series. By interpolation the author filled the gaps and so was able to make use of nearly all the data. Interpolated yields are of course unsatisfactory, but the method followed appeared more adequate to the purpose than the limitations set by the small number of years for which the records are complete. The average yields from all places at the various spacings are as follows:

Distance in inches	Lint-cotton per acre in pounds
3	[illegible]
6	225
9	230
12	234
15	230
18	232
21	232
24	227
27	226
30	225
33	222
36	203

The variation in yield from one spacing to another, as shown by the averages, is not highly pronounced and makes difficult the drawing of a satisfactory conclusion. It is noticeable, however, that there is a positive and progressive increase in the yields from the 3-inch to the 12-inch spacing, that from the 12-inch through the 21-inch spacing the yields are nearly constant with an average of 232 pounds per acre, and that from the 21-inch to the 36-inch spacing there is a consistent decrease in yield. The conclusion is reached, therefore, that no appreciable effect on the yield was produced by a variation of 4½ inches either way from 16½-inch spacing, which is the average of the 12- to 21-inch spacings giving the highest yields.

The second method of arriving at a conclusion is to make use in each year's trial of the range of spacing which gave highest yields within the limits of error. This method permits the utilization of all the data for the total of 66 years, and appears to the author to be

of considerably more merit than the first method. Table 2 gives the results by years for each place.

The data of Table 2 show that at practically every place widely different results were secured during the experimental period. In the nine years' trial at Beeville, for example, the allowable differences in spacing were from 3 to 6 inches for two years, 8 to 9 inches for two years, 12 to 15 inches for four years, and 21 inches for one year. With all the data taken into consideration, the frequency of the allowable differences is summarized as follows:

Allowable difference in inches	Times of occurrence
2–4	5
5–7	14
8–10	9
11–13	13
14–16	6
17–19	3
20–22	5
23–25	4
26–28	6
29–31	0
32–34	1
Total	66

Attention is called to the following considerations:

1. That in 55% of the trials the allowable difference was between 5 and 13 inches, or from 2½ to 6½ inches either way from the average "best" spacing.

2. That a variation of 5 to 7 inches, or 2½ to 3½ inches either way from the average "best" spacing, is compatible with 92% of the trials.

3. That the 8% showing that less than a 5-inch variation was allowable is too small an amount, especially in view of the possibility of experimental error, to be a serious objection to the general conclusion which follows.

The data show fairly conclusively that with 3-foot rows 3 inches may be allowed either way from the "best" spacing without noticeable effect on the yield.

It is well known that for best yields many crops require a larger number of plants on rich land than on poor land. Corn is cited as a conspicuous example in this respect. Certain other crops, of which cotton was supposed to be an example, have been considered to do best with a smaller number of plants on rich land than on poor

TABLE 2.—*Spacings which gave yields within the limits of error with one plant per hill in 3-foot rows.*

Place	Year	Spacing Low	Spacing High	Allowable difference
		Inches	*Inches*	*Inches*
Angleton	1917	12	18	6
	1918	3	15	12
	1919	12	15	3
	1920	6	33	27
	1921	15	18	3
	1922	24	36	12
	1923	6	9	3
	1924	3	36	33
Beeville	1915	6	12	6
	1917	6	27	21
	1918	15	30	15
	1919	12	15	3
	1920	9	15	8
	1922	18	30	12
	1923	12	21	9
	1924	12	27	15
	1925	12	24	12
Chillicothe	1919	12	18	6
	1920	18	30	12
	1921	12	30	18
	1922	18	30	12
	1924	18	30	12
College Station	1914	9	15	6
	1915	24	30	6
	1916	3	9	6
	1917	12	33	21
	1919	3	15	12
Lubbock	1913	9	18	9
	1914	6	21	15
	1915	6	18	12
	1916	3	9	6
	1917	3	12	9
	1918	12	36	24
	1919	6	33	27
	1920	6	33	27
	1921	9	18	9
	1922	21	27	6
	1923	3	9	6
	1924	9	33	24

TABLE 2.—*Continued.*

Place	Year	Spacing Low *Inches*	Spacing High *Inches*	Allowable difference *Inches*
Nacogdoches	1915	21	33	12
	1916	18	30	12
	1917	9	33	24
	1918	3	30	27
	1919	18	33	15
	1920	12	33	21
Pecos	1916	15	18	3
	1917	9	15	6
	1919	9	18	9
Spur	1914	6	24	18
	1915	6	21	15
	1917	6	12	6
	1919	12	30	18
	1921	9	18	9
	1922	3	24	21
	1923	9	18	9
	1924	3	24	21
Temple	1915	24	33	9
	1916	12	18	6
	1917	18	24	6
	1918	24	36	12
	1919	6	33	27
	1920	18	33	15
	1921	9	33	24
Troup	1915	27	33	6
	1917	6	33	27
	1918	21	33	12

land. Fig. 1 admits of at least an indication of a relationship, for with this object in view median lines are drawn, each being the median, or average, within certain limits of yield. They indicate, contrary to popular opinion, that the best spacing is closer under conditions of high than of low productivity, but that the difference is small, according to the chart only some 2½ inches between extreme conditions.

EXPERIMENTS WITH TWO PLANTS PER HILL

Data as to the best spacing with two plants per hill were obtained at five different places. The results, which varied much as in the single-plant data, are given in Table 1 and are depicted in Fig. 2. The averages are as follows:

Place	Years of trial	"Best" spacing in inches
Beeville	7	18
College Station	4	19
Nacogdoches	5	25
Temple	6	20
Troup	3	21
Total number of years	25	Average 21

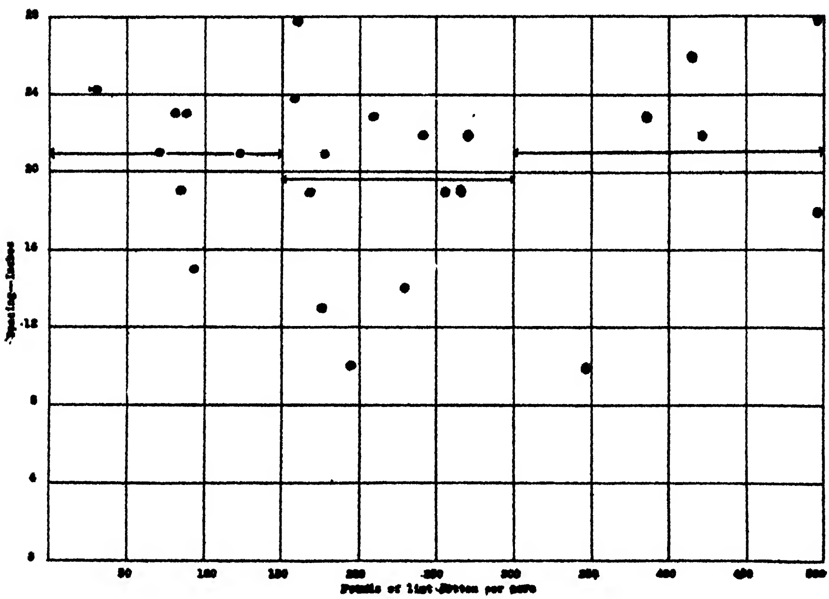

FIG. 2.

The extremes are 18 and 25 inches, and the average is 21 inches. If, as in the one-plant series, each year's trial be given equal weight, the average is found to be 20 inches.

If the acre yields obtained from the best spacing of one plant per hill be compared with those from two plants per hill, the latter appear to advantage. There is, however, much irregularity in the yields, and it is of such a nature as to indicate dissimilar soil or other experimental conditions in the two sets. This view is borne out by the fact that of the 25 trials, 12 are favorable to one plant per hill and 12 to two plants per hill, while in one trial the yields are equal.

DATA FROM STATES OTHER THAN TEXAS

The data from the other southern states are scattered and are not strictly comparable because the experiments were planned differently.

The results are brought together, however, on a similar basis in Table 3, and the data for one stalk per hill are shown graphically in Fig. 3.

EXPERIMENT WITH ONE PLANT PER HILL

The data of Table 3 resemble the Texas data of Table 1 in that wide variations in "best" spacing occur not only when all the results are considered as a whole, as might be expected, but also in the case of the states as individuals. In the data from Alabama the extremes are 8 and 23 inches, from Louisiana 9 and 21 inches, from Mississippi 6 and 21 inches, from North Carolina 13 and 20 inches, from South

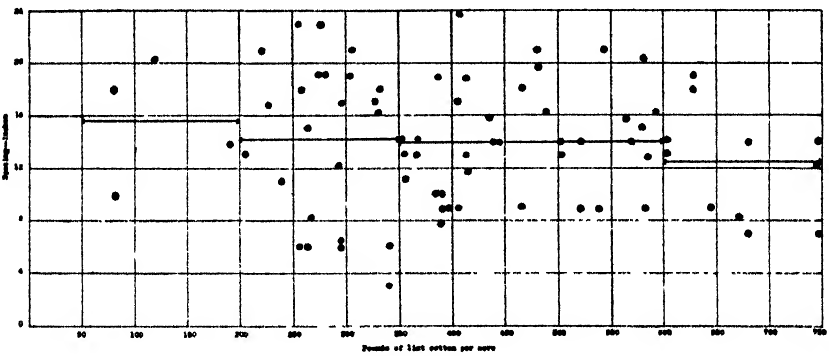

FIG. 3.

Carolina 3 and 24 inches, and from Tennessee 7 and 20 inches. However, if the state averages be brought together for comparison, considerable uniformity is shown. The averages are as follows:

State	Years of trial	Average of "best" spacings in inches
Alabama	3	16
Louisiana	6	16
Mississippi	21	13
North Carolina	19	17
South Carolina	8	12
Tennessee	13	11
Miscellaneous	7	15
Total number of years	77	Average per state 14

The extremes are 11 and 17 inches and the general average is 14 inches.

The median lines of Fig. 3 indicate, as in the case of the Texas data, that somewhat closer spacing is called for under conditions of high productivity than under low productivity.

TABLE 3.—*Yields of lint cotton per acre from tests in various states on the spacing of cotton with "best" spacing on the basis of 3½-foot rows.*

State	Place	Year	One plant per hill Yield	One plant per hill Best spacing	Two plants per hill Yield	Two plants per hill Best spacing	Three plants per hill Yield	Three plants per hill Best spacing	Four plants per hill Yield	Four plants per hill Best spacing
			Pounds	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*
Alabama	Auburn (2)	1924	327	17	342	26	338	29	326	26
	(6- to 36-inch spacing)	1925	274	23	282	24	274	26	266	30
		1926	267	8	243	17	256	26	253	21
	State average		289	16	289	22	289	27	282	26
Louisiana	Calhoun	1889	(3) 645	9	677	16				
	(8- to 24-inch spacing)	1890	(4) 501	14	545	16				
		1891	(5) 545	21	595	23				
		1892	(6) 305	21	315	21				
		1893	(7) 357	11	337	18				
	Baton Rouge	1893	(8) 629	18	647	24				
	State average		497	16	519	20				
Mississippi	Central Station (9)	1910	787	14						
	12- to 36-inch spacing)	1911	480	21						
		1912	444	14						
		1913	680	14						
		1914	518	14						
		1915	369	14						
		1916	192	14						
		1917	296	6						
		Average	471	14						
	Holly Springs	1917	(10) 261	6						
	(6- to 24-inch spacing)	1920	(11) 416	12						
		1921	(12) 464	9						
		1922	(13) 297	6						
		1924	(14) 439	14						
		1925	(15) 540	9						

		1926 (16)	518	9
		Average	419	9
	Delta Station	1912 (9)	256	18
	(8- to 24-inch spacing	1916 (9)	435	16
		1920 (9)	390	8
		1922 (17)	330	16
		Average	353	15
	Poplarville	1920 (18)	405	9
	(6- to 24-inch spacing)	1921 (19)	342	6
		Average	374	8
	State average		422	13
North	Edgcombe (20)	1901	466	18
Carolina	(12- to 24-inch spacing)	1902	502	13
		1903	582	20
		1905	581	15
		Average	533	17
	Iredell (20)	1903	253	23
	(12- to 24-inch spacing)	1904	277	19
		1905	389	19
		1906	595	16
		1907	481	20
		1908	492	16
		Average	415	19
	Raleigh (21)	1st	354	13
	(12- to 24-inch spacing)	2nd	275	19
		3rd	301	19
		4th	405	17
		5th	628	19
		1922	413	13
		Average	396	17

TABLE 3.—*Yields of lint cotton per acre from tests in various states on the spacing of cotton with "best" spacing on the basis of 3½-foot rows.*

State	Place	Year	One plant per hill Yield	One plant per hill Best spacing	Two plants per hill Yield	Two plants per hill Best spacing	Three plants per hill Yield	Three plants per hill Best spacing	Four plants per hill Yield	Four plants per hill Best spacing
			Pounds	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*
	Red Springs (21)	2nd	414	19						
	(12- to 24-inch spacing)	3rd	298	17						
		4th	266	15						
		Average	326	17						
	State average		420	17						
South	Florence (22)	1923	519	14	535	21	553	14	422	24
Carolina	(12- to 24-inch spacing)	1924	500	14	465	17	461	21	507	27
		1925	573	21	618	17	607	21	580	21
		Average	531	16	539	18	540	19	503	24
	Clemson College (23)	1921	340	3						
		1923	406	24						
		Average	373	14						
	Florence (22)	1922	256	6						
		1923	584	13						
		1924	568	14						
		1925	585	9						
		Average	498	11						
	Summerville (23)	1921	82	18						
		1922	205	13						
		Average	144	16						
	State average		378	13	539	18	540	19	503	24
Tennessee	Jackson (24)	1915	684	7						
	(3- to 24-inch spacing)	1916	673	8						
		1917	395	9						
		1918	365	13						
		1919	750	12						

		1920	564	16						
		1921	807	7						
		1922	600	13						
		1924 (25)	391	10						
		1925 (25)	400	9						
		1926 (25)	235	11						
		1927 (25)	386	10						
	Lexington	1922 (25)	121	20						
	State average		490	11						
(Miscellaneous)										
Arkansas	Scotts	1917 (26)	226	17						
		1918 (27)	601	3						
		1921 (28)	351	14						
Georgia	Experiment	1921 (28)	83	10						
		1922 (28)	296	12						
Oklahoma	Stillwater	1922 (28)	222	21						
Alabama	Auburn	1922 (28)	332	18	367	21				
	Average		302	14						

Summary by States

	Years of trial								
Alabama	3	289	16	289	22	289	27	282	26
Louisiana	6	497	16	519	20				
Mississippi	21	422	13						
North Carolina	19	420	17						
South Carolina	8	531	12	539	18	540	19	503	24
Tennessee	13	490	11						
Miscellaneous	7	302	14						
Average		422	14	449	20	415	23	398	25

EXPERIMENTS WITH TWO OR MORE PLANTS PER HILL

Data from systematic experiments on spacing with two or more plants per hill were found to be limited to three states, *viz.*, Alabama, Louisiana, and South Carolina. The results are as follows:

State	Years of trial	Average of "best" spacing 2 plants	3 plants	4 plants
		Inches	*Inches*	*Inches*
Alabama	3	22	27	26
Louisiana	6	20		
South Carolina	3	18	19	24
Average per state		20	23	25

The results are fairly concordant except as to three plants to the hill, but when averaged the data appear in harmony. It was found that 20-inch spacing was best for two plants to the hill; 23-inch for three plants; and 25-inch for four plants.

The comparative yields from the best spacing for one plant per hill with those from two or more plants, as afforded by the average of the Alabama and South Carolina data, are as follows:

1 plant per hill	410 pounds
2 plants per hill	414 pounds
3 plants per hill	415 pounds
4 plants per hill	398 pounds

The evidence is slightly in favor of two or three plants to the hill rather than one plant, but is unfavorable to four plants per hill.

COMPARISON BETWEEN THE DATA FROM TEXAS AND FROM OTHER STATES

Probably because of the great difference between the soil and climatic conditions of Texas and of the states east of the Mississippi, the opinion has been prevalent that the data obtained in Texas would not apply in the East. But the data from each section, as previously discussed and as summarized below, show closely parallel results A further comparison can be made to advantage, however, by means of the data for each section as depicted in Figs. 1 and 3 in the construction of frequency curves which allow the two sets to be compared. This comparison on a percentage basis is shown in Fig. 4, in which the curve made by the solid line represents the frequency at which the "best" spacing occurred at 4-inch intervals from 4 to 28 inches in the data from Texas. The frequency curve of the data from the other states is shown by the broken line. The two curves are similar in that for each the "best" spacing occurs

most frequently within the 12- to 16-inch limits. There is, however, an indication that slightly wider spacing may be warranted under the Texas conditions, because the falling off in the frequencies from 16 to 28 inches is appreciably more precipitate in the data from the eastern states than in those from Texas. Also, the frequencies below a 12-inch spacing are less for Texas than for the other states.

In connection with this comparison the fact may well be taken into consideration that the Texas data were nearly all secured in

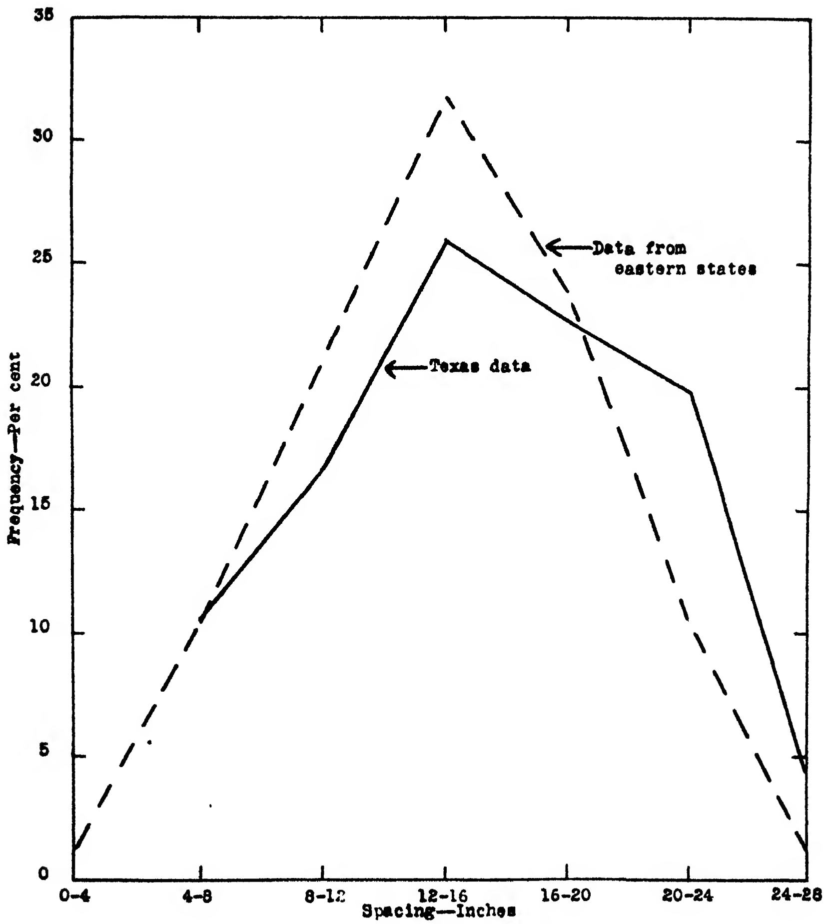

FIG. 4.

spacings from 3 inches upward. Had the experimental spacings begun at 6 inches or more, the average "best" spacing would have been increased slightly. To illustrate this point, if the yields in any series were the same, within the limits of error, from 3 to, say,

21 inches, the average would be 12 inches, but if the spacing began at 6 inches the average best spacing would be 13½ inches. As a matter of fact, this factor enters into only a small part of the trials because the "best" spacings seldom include the 3-inch distance. The effect, however, would tend to lower the Texas average because in the trials in other states 6, 8, or even 12 inches were the closest spacings included in numerous instances. As an offset, attention is called to the fact that the Texas data were secured under conditions of lower yield, on the average, than was the case for the data from the other states, and, as has been pointed out, conditions of low yield tend to increase the distance of "best" spacing.

The fact that the results were so much alike under such widely different conditions as those of Texas and the states to the east is a strong indication that there is a definite and common "best" spacing of universal application. This may be the case, but the fact that there are factors which bring about widely different results in different years, as found in any long-continued series of experiments, suggests that exceptions may be found where either closer or wider spacing than the general average would be warranted.

DEFERRED THINNING AS A CAUSE OF CLOSE-SPACING RESULTS

Lack of time prevented the author from attempting to investigate the more prominent possible reasons for the great variations in the data secured in different years in any long-continued series. Why should a 6-inch spacing be best one year and a 20-inch spacing be best another year? Without doubt inequalities in the soil of the experimental plats and "clerical" errors account for some of the results. Climatic and soil conditions are probably important factors in the case. It is also probable that a number of results are in favor

SUMMARY AS TO THE BEST SPACING OF COTTON

Source of data	Width of row *Feet*	One plant per hill *Inches*	Two plants per hill *Inches*	Three plants per hill *Inches*	Four plants per hill *Inches*
Texas.	3½	15	20	—	—
Other states.	3½	14	20	23	25
Allowable limits. .	—	11–16	17–22	21–26	22–28
	Equivalent Spacings for 3- and 4-foot rows				
Texas.	3	17	23	—	—
Other states.	3	16	23	27	29
Allowable limits. .	—	13–19	20–26	24–30	26–32
Texas.	4	13	18	—	—
Other states.	4	12	18	20	22
Allowable limits. .	—	10–14	15–20	18–22	20–24

of close spacing because of unintentional deferred thinning. That is, the thinning had been postponed, necessarily or otherwise, until the deferred-thinning effect was obtained. The subject of deferred thinning has received considerable attention for the last dozen years, and it has been demonstrated repeatedly that thinning must be done early, say, when the plants have only four to six leaves, else reduced yields follow, the reduction being proportionate not only to the lateness of thinning or the size of the plants, but also to the extent of the thinning. That is, the effect is least evident where the least thinning is done and most evident where the most thinning is done. The exact stage of growth at which thinning reacts appreciably in this way may not have been determined, but it is noteworthy that in the Texas experiments comparisons were made between "normal thinning" and thinning when the plants were only about 6 inches tall, the latter being defined as "deferred thinning." Even under this condition the results show that in general "normal thinning" produced larger yields than "deferred thinning."

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4. SOME ECONOMICS OF COTTON PRODUCTION IN THE SOUTHEASTERN STATES[1]

F. W. Gist[2]

The economic problem of agriculture, expressed in one word, is "income." If the cotton grower anywhere has a sufficient income to meet his requirements he has no problem. If he has not such an income then he shall be looking for the reason why and the source of correcting the evil. Has the southeastern cotton grower a sufficient income? In presenting the facts of record we shall confine ourselves to those five states which grow cotton as a more or less universal product of all the farms, *viz.*, Alabama, Georgia, Mississippi, North Carolina, and South Carolina. Likewise, for comparison with western territory, we shall study only Texas, Oklahoma, Arkansas, and Louisiana. Other cotton-producing states in both areas have such wide sections without cotton that official statistics may not be readily used within state lines.

THE FARM INCOME

An accurate knowledge of farm income, correctly defined, may not be had from official sources, but the following statement (Table 1) may be accepted as at least indicating comparable facts on this point. Assuming that Georgia and South Carolina are more or less typical of the eastern cotton-producing states and Texas and Oklahoma of the western area, certain data are presented for these four states. The basic figures are taken from the 1925 census of agriculture, except that the item of "value of crop and livestock products" is taken from the estimates of the United States Department of Agriculture as probably being more nearly complete for that item for the year 1924 to which these data refer.

The value of crops and livestock is in each case an average of the two years 1924 and 1925 as balancing each state between good and bad seasons. The item of "interest at 14% of investment" is assumed as covering taxes, upkeep, replacements, and rents, the latter being necessary for tenants but coming back to farm owner operators. This percentage may or may not cover in each case the items of necessary outlay indicated, but it is assumed as being at least fairly typical and as placing all farms on an equal basis of net income. Income as here used is not, of course, actual cash income, but is

[1]Paper read as part of the symposium on "Cotton" at the meeting of the Society held in Chicago, Ill., Nov. 17, 1927.

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TABLE 1.—*Farm income in four typical cotton states.*[a]

	Georgia	So. Carolina	Texas	Oklahoma
Total farm investment...	$686,673	$523,084	$3,471,867	$1,210,135
Interest at 14%........	96,134	73,332	486,061	169,419
Spent for fertilizers.....	21,100	24,306	4,124	203
Spent for feed..........	6,305	2,322	34,661	15,618
Spent for labor... ...	11,926	8,159	71,933	26,238
Total cash outlay... .	$135,465	$108,119	$596,779	$211,478
Value of crops and livestock	340,000	221,000	1,093,000	522,000
Net assumed income. .	$204,535	$112,881	$496,221	$310,522
Percentage of investment	29.8	21.6	14.3	25.7
Farm population........	1,310	912	2,115	926
Net income per capita.	$159	$124	$234	$335

[a]Three ciphers omitted from aggregates.

thought to be fair as including a large part of the consumption for family and farm purposes.

The National Bureau of Economic Research gives an annual average income per capita of farm population for these four States, including the years 1919, 1920, and 1921, as follows: Georgia, $168; South Carolina, $196; Texas, $286; Oklahoma, $263. These are

TABLE 2.—*Per capita income of non-farm and farm groups in nine principal cotton-producing states and for certain other States, 1919.*

	Non-farm	Farm
Eastern cotton states:		
Alabama..........	$483	$200
Georgia..........	552	256
Mississippi..........	541	241
North Carolina..........	500	275
South Carolina..........	555	298
Average..........	$526	$252
Western cotton states:		
Texas..........	$666	$360
Oklahoma..........	680	354
Arkansas..........	562	243
Louisiana..........	547	240
Average..........	$614	$299
New England states..........	$744	$406
Middle Atlantic..........	812	507
East North Central..........	742	427
West North Central..........	666	463
Mountain..........	686	539
Pacific..........	798	772
United States..........	$723	$362

calculated on a different basis, and are entirely estimated. The two sets of figures are at least in somewhat the same direction.

From our own calculations, as indicated above, the average net income per capita of farm population for other cotton States is as follows: Alabama, \$179; Mississippi, \$203; North Carolina, \$160; Arkansas, \$205; and Louisiana, \$193. The point at issue is whether the farm income is sufficient to maintain the farm family in an acceptable standard of living. Before deciding this question, it may be well to consider the incomes of farmers in other sections and the incomes of other groups of workers in comparison. For this purpose we submit a comparative statement (Table 2) from the National Bureau of Economic Research for the year 1919, one of the best farm years in recent times, using certain typical states as between the farm and non-farm groups.

TABLE 3.—*Income from cotton in representative states.*

	Per acre				
	Gross value of cotton	Cost of fertilizers	Net value of cotton	Acres per capita on cotton farms	Net value of cotton per capita on cotton farms
Eastern cotton states:					
Alabama	\$31.72	\$3.54	\$28.18	\$3.37	\$95.00
Georgia.	29.90	3.79	26.11	3.10	91.00
Mississippi .	42.51	1.87	40.64	3.41	138.55
North Carolina....	43.44	6.72	36.72	3.66	135.30
South Carolina. ..	30.11	4.67	25.44	3.01	76.60
Western cotton states:					
Texas	25.22	.23	24.99	10.37	259.25
Oklahoma	31.11	.06	31.05	8.45	265.75
Arkansas.......	32.37	1.24	31.13	4.67	145.25
Louisiana.. ..	33.64	1.59	32.05	3.42	109.70

It is true that the non-farm population has expenses which the farmer does not have, such as house rent, fuel, clothing standards, etc. But it is seen that the ratio of farm to non-farm income in the eastern cotton states is lower than for the western states and the lowest of all sections, these ratios being as follows:

	Ratio farm to non-farm income
Five eastern cotton states.......	48.0
Four western cotton states......	48.7
New England states............	54.6
Middle Atlantic states..........	61.2
East North Central............	56.2
West North Central............	69.5
Mountain.....................	78.6
Pacific........................	96.7
United States................	50.1

Since cotton furnishes something like 70 to 80% of the cash income of those farmers producing cotton, the value of cotton produced may be said to measure the income of the cotton grower. Table 3 shows the average value of cotton produced per acre, the average acres per capita of farm population, and the average value of cotton per capita of farm population in the states named for the years 1924, 1925, and 1926.

From all these data we are forced to the conclusion that the cotton grower, especially of the eastern cotton states, is receiving an income gross or net, below that of his neighboring farmers in other sections, and therefore, much below the income of other groups, since all farmers have an income below that of the non-farm groups. Therefore, the cotton grower's family must be living at a standard much below that which is available to the average family of the United States. Probably the average farm family of five persons might get along fairly well with the annual income from cotton shown just above in Texas and Oklahoma, averaging $1,296 and $1,329, respectively; but one would hesitate to undertake to support a family of five and educate three children, even without the ordinary pleasures of life, on the income of South Carolina cotton growers, averaging $383, or even that of Alabama or Georgia, averaging $475 and $555, respectively.

UNIT PRICE OF COTTON

Unit price is of supreme importance in the successful distribution of any commodity. All producers are entitled to a fair price for their product. What is a fair price? It may be defined as that price

TABLE 4.—*Index numbers of cotton prices and of prices farmers paid for the period 1917–1926, inclusive.*[a]

	Cotton prices	Prices farmers paid
1917	177	182
1918	238	188
1919	241	199
1920	250	241
1921	101	167
1922	156	168
1923	218	171
1924	216	162
1925	179	164
1926	122	161
Ten year average	190	180
1907–1921	201	195
1922–1926	178	165

[a]100 equals prices for 1909–1914.

which is in just ratio to the prices of commodities for which the products must be exchanged. If his products are selling at a price below that of the other commodities, the producer is not receiving a 100-cent dollar; if they are selling at a rate above the other commodities, he is profiting at the expense of others.

A statement (Table 4) of the price of cotton in terms of index numbers measured by a given basis in comparison with the prices of commodities farmers buy, measured by the same basis, will throw light on this question.

Measured by both ten- and five- year averages, it is seen that the price of cotton has been above the average of commodities farmers buy. Therefore, on the whole, we cannot say that the matter of prices per unit has operated against the cotton grower but rather in his favor. Unfortunately, however, two years in the ten, both at the end of a five-year period, the unit price was not only materially but drastically below the prices farmers paid. In 1921 cotton prices were 56 points, or about 33%, below his purchased commodities, while in 1926 they were 39 points, or slightly more than 24% below. It is true that in 1918 the price of cotton was 50 points, or nearly 30%, and in 1924 it was 54 points, or 33%, above the prices the grower had to pay. In a business conducted as most industrials are, these conditions would have offset each other. The cotton grower, however, especially in the southeast, does not do business that way. In the first place, his purchases are made chiefly in advance of his paying ability, thus precluding adjustment of his purchases to his buying power. Secondly, he is more or less prone to replenish his larders and a good bit more in prosperous years, dissipating the reserves which industry would hold against lean years. Thus, the problem becomes one either of stabilizing cotton prices or of inducing the grower to turn to the cash basis of purchasing. The latter seems to be hopeless, at least with a large portion of those who produce cotton, while price stabilization has not yet been worked out, the only approach to it being offered by cooperative marketing, which has as yet reached less than 10% of the cotton producers.

THE PROBLEMS OF THE COTTON GROWER

We have come to believe that the chief problems of the cotton grower are poor land, inefficient labor, costly credit, costly distribution, boll weevil damage, and too much utter dependence on cotton.

SOIL FERTILITY

It was shown in Table 3 that for the past three years the bill of the eastern cotton farmer for soil fertility in the form of commercial

fertilizers has been quite high. This is brought out still better in Table 5 which gives the average yield of cotton, the average value of the crop, the average cost of fertilizers, and the net value of cotton per acre for the nine states under discussion for a five-year period.

TABLE 5.—*Fertilizer costs and average returns from cotton for a five-year period in nine representative states.*

	Acre yield, pounds	Acre value	Fertilizer cost	Net value
Eastern states:				
Alabama........	154	$33.11	$3.42	$29.69
Georgia.........	135	29.03	3.72	25.31
Mississippi.. .	188	40.42	1.66	38.76
North Carolina...	260	55.93	6.54	49.39
South Carolina...	162	34.83	4.40	30.43
Average.......	179	$38.44	$3.95	$34.50
Western states:				
Texas........	135	$ 9.03	$.18	$28.85
Oklahoma.......	145	31.17	.02	31.15
Arkansas........	168	36.12	1.10	35.02
Louisiana..... .	169	36.33	1.48	34.85
Average.......	154	$33.16	$.69	$32.47

It is interesting to note that the average yield in Texas with almost no fertilizer has been equal to that of Georgia, the net value being about $3.50 greater in the western state. Also, the net value per acre in Oklahoma has been greater than in either Alabama or South Carolina and the acre yield in both Arkansas and Louisiana has exceeded that of the two eastern states named. In Mississippi and North Carolina yields have been outstanding, the net value in the latter state exceeding that of the former. In the eastern states 85% of the acreage is treated with commercial fertilizers, while only 21% of the western acreage is so treated.

LABOR EFFICIENCY

The actual number of farm workers is not known at the present moment. Presumably the number has diminished in recent years, and there has been some considerable improvement in the efficiency of those remaining. However, there is still a marked difference in farm labor efficiency in the different states. Some measure of efficiency may be had in the number of acres cultivated, in the number of workstock employed, and in the implements found on the farms. As a means of making this measurement the farm population 10 years of age and over is used. This is not accurate, because in some states a large proportion of women and children perform farm labor, while in other states few or none do so. However, such

a basis is comparable in the absence of better data. Table 6 shows for the states here discussed the ratio of mature horses and mules, of the value of farm implements, and of the crop acreage to the farm population 10 years old and over.

TABLE 6.—*Measuring of labor efficiency in nine representative cotton states.*

	Horses and mules	Farm implement value	Crop acres
Eastern states:			
Alabama	0.45	$28.46	7.9
Georgia	0.42	28.83	8.7
Mississippi	0.54	34.54	6.9
North Carolina	0.49	46.20	5.5
South Carolina	0.39	36.36	6.8
Average	0.47	34.88	7.2
Western states:			
Texas	1.12	91.37	17.4
Oklahoma	1.34	85.64	21.7
Arkansas	0.96	59.54	11.9
Louisana	0.59	48.10	7.0
Average	1.00	71.16	14.5

The better showing in the western group may be explained by the use of improved implements of cultivation which utilize two horses instead of one, to some extent by the better distribution of labor due to diversified farming, and in part by the acreage devoted to grain which needs no cultivation. However, the cotton acres per farm capita 10 years and over may be measured on those farms reporting cotton in 1925 as follows:

	Cotton acres
Alabama	5.1
Georgia	5.0
Mississippi	5.2
North Carolina	3.4
South Carolina	4.5
Average	4.6
Texas	14.2
Oklahoma	12.1
Arkansas	9.6
Louisiana	5.3
Average	10.3

Since man labor is the most costly element in the production of any commodity and since industry has long ago turned to quantity

production by supplementing man labor with machines, the costly processes of man culture in the cotton fields must give way if the eastern part of the cotton belt is to maintain profitable production at prices the world will pay.

On this point eastern cotton fields have a problem of their own. A large portion of the farm tenants are nothing but negro farm laborers paid with a portion of their product. The hired labor is practically all colored. This labor is permanently fixed on the soil and must be maintained whether it works or not. On the contrary, labor in Texas and Oklahoma is more generally hired when needed and is of a type that does not become a burden on the community when not employed.

FARM CREDITS

Not much data of a statistical nature are available on this subject. One thing we do know from purely personal contact is that credits are costly to the cotton grower in the southeastern states. Only in recent years has local banking capital been sufficient to be available to the farmer.

We obtained some data on the subject in Alabama about a year ago from both bankers and farm owners. Only 35% of the farmers reporting to us borrowed money from the banks and 71% of these used their loans to pay cash for what they bought. It developed that 29% of the farm owners still buy on open store credit and only about the same proportion of tenant farmers patronize the banks. The average rate of bank credit for short-term loans was 8.1%, and bank borrowers were able to save about 8% by this method. The difference between cash and time store purchases was a fraction over 16%. The savings were distributed as follows: On fertilizers, 18%; on feed, 14%; on machinery, 16%; and on family supplies, 17%. The inquiry also brought out the fact that 33.5% of the bank loans were used to buy fertilizers, 14.5% to buy feed, 7.5% to buy livestock, 14.0% to pay labor, and 30.5% for all other purposes mostly family supplies. Very recently the intermediate credit system has offered some reduction in the cost of borrowed money, but as yet it is not being used to any great extent, due probably to the inability of the farmer to obtain his loan so promptly as from local sources. The farm bureau has by its activities unquestionably brought down the rate of interest on short-time loans, as has the Federal Land Banks on long-time mortgages.

In this latter field dependable statistics are also lacking. The census reports only as is reported to its enumerators by farm owners and does not record the mortgages on tenant farms nor on many of

the farm owners. Such as are available indicate that the South is not in much different shape from the rest of the country, perhaps showing a less portion of farms mortgaged and less volume of credit in proportion to value. The 1925 census of agriculture gives the following as the percentages of owned farms reporting mortgages and the percentage of mortgage debt to total value for the states named:

	Percentage mortgaged	Ratio debt to value
Alabama	29.9	41.9
Georgia	27.2	41.8
Mississippi	33.1	41.2
North Carolina	19.3	36.4
South Carolina	25.9	40.6
Texas	33.9	35.3
Oklahoma	48.3	39.7
Arkansas	32.9	40.1
Louisiana	27.5	42.9
Iowa	55.6	49.2
California	46.3	33.8
Illinois	35.5	40.8
New York	38.7	41.6

One is inclined to wonder whether farm credit has not been too easily available, whether farmers have not taken too free advantage of it, and whether the real problem is not retrenchment rather than cheaper credit. On the other hand, a very large proportion of all business enterprises in this country is conducted on credit and the farmer is not on the whole so greatly burdened on this score.

NATURAL ENEMIES OF COTTON

No scientific estimate of the damage to cotton by its natural enemies has ever been made. It is doubtful if such an estimate can be made. Heavy damage, followed by low yields, has resulted in high prices, whereas if no damage had occurred the price would probably have been enough lower to offset the difference in value From the standpoint of production, many things have interfered with cotton. An estimate has been made by the United States Department of Agriculture of the percentage loss from a full yield for several of the major crops. These estimates have been merely the opinion of crop reporters and have no scientific background and may be accepted as relative only. The average loss in percentage of full yield of the five principal crops of the United States for the ten years 1915–1924, was as follows:

	Loss%
Cotton	40.36
Corn	28.22
Wheat	30.31
Oats	23.39
Potatoes	28.75

Of the loss to cotton 19.18% of a full yield, or nearly one-half the total loss, was charged to insects of which 15.43%, or about 70% of the insect damage, was said to be due to the ravages of the boll weevil. A little more than one-half the damage to cotton was charged to climatic influences. Of course if the cotton produced in ten years was only 60% of what the soil would have yielded if uninfluenced by weather, insects, and plant diseases, the absence of these influences would have left us with an average of 18,333,000 bales per annum instead of slightly more than 11,000,000. Who can say, therefore, whether nature has not beneficently controlled production when the grower of cotton would not?

For the five-year period 1920 to 1924, the nine states under consideration have reported boll weevil damage at the following average rate per annum:

	Loss in percentage of full yield
Alabama	27.64
Georgia	34.14
Mississippi	25.65
North Carolina	7.06
South Carolina	25.62
Texas	17.48
Oklahoma	19.82
Arkansas	15.80
Louisiana	22.65

Leaving out North Carolina, which so far has not suffered materially, the four eastern states had an average loss of 28.26% annually, while the four western states had 18.94%. Evidently, under average conditions, the boll weevil is more of a problem to the eastern cotton grower than to the western grower.

Another important consideration in all cotton states is the possible maximum damage which the weevil may occasion. This is shown relatively in the high peak of damage sustained in each state during the five-year period of 1920 to 1924 as follows:

	Maximum loss%
Alabama (1920)	36.03
Georgia (1921)	45.12
Mississippi (1920)	32.25
North Carolina (1923)	12.97
South Carolina (1922)	40.48
Texas (1921)	33.66
Oklahoma (1921)	41.36
Arkansas (1921)	21.84
Louisiana (1921)	34.80
All states (1921)	30.98

With regard to control measures, our observation is that in Alabama at least farmers have adopted cultural and fertilization methods which have quite noticeably increased their efficiency in producing cotton in spite of the weevil. So few of them have practiced poisoning that one naturally questions if it is worth while to continue to stress poisoning as a means of control.

COST OF PRODUCTION

No economic discussion would be complete without reference to the cost of production, and yet any attempt to discuss the cost of producing cotton at once runs one against a blank wall. No determination of cost has ever been made which is acceptable to either producer or consumer. All investigations of an official nature have sought only the opinions of producers on the basis of averages per acre. Assuming that these opinions are fairly close to the facts, all we have as a result is the average cost per pound of lint cotton or the cost per acre.

An inquiry made in Alabama based on reports of actual operations gave costs of lint ranging all the way from 4 cents to $1.07 per pound. For the past few years the Washington office has been making an opinion inquiry and publishing results by yield groups for the entire cotton belt. The one thing of positive value from these reports is that the higher the yield the lower the cost per unit, confirming a well-known fact relating to all production whether in agriculture or industry.

Access to this same inquiry for 1926 in a tabulation of the reports compiled by states shows that, as usual, the acre-yields of those reporting were higher than the average. The costs per unit determined on these higher yields have been reduced to the equivalent basis of the officially estimated yields for each state. The two

sets of results are given below for their comparative value and interest:

	Average cost per pound	
	For those reporting	Reduced to estimated yields
Alabama	$0.12	$0.136
Georgia	.13	.146
Mississippi	.12	.133
North Carolina	.14	.150
South Carolina	.16	.177
Texas	.15	.154
Oklahoma	.11	.127
Arkansas	.14	.147
Louisiana	.15	.154

These figures allow credit for the seed. The actual average price of cotton per pound for 1926 is not yet known; but assuming that it was somewhere around 12 cents as actually sold, it is seen that even Oklahoma with the lowest cost on her average yield, did not realize the cost of production on the basis calculated. Only those obtaining considerably above the average yields in all states met their cost.

In the matter of computing the cost of cotton production the usual practices of growers in most states do not admit of the generally accepted rules of cost accounting being applied. These figures include the cost of man labor in the various stages of production at the customary wage rate, while most cotton growers perform their own labor. This is especially true of the tenant farmer. In all these cases the farmer is not particularly concerned with the cost of labor, since he feels that he puts in the year anyway and that his total farm production is so much return for that year. Therefore, discussions of labor returns to be of interest to farmers of this type must be directed to showing how a larger gross return may be had by larger accomplishments for the year, rather than to argue theoretic labor costs.

With this in view we have studied the 1926 figures from the point of view of what was left to the grower from an acre of cotton after the necessary cash outlay was accounted for. Treating rents in the same manner as labor, assuming them to be returned to the farmer in the case of owners, and subtracting the reported cash costs on the basis of reported yields from the value of the crop per acre at 12 cents per pound of lint, we get the following sums as labor and rent returns to farm owner operators and as labor returns to tenant operators:

	Owners	Tenants
Alabama	$16.54	$13.17
Georgia	12.68	9.37
Mississippi	21.72	16.54
North Carolina	22.62	14.21
South Carolina	11.63	6.41
Texas	13.23	4.65
Oklahoma	17.68	10.58
Arkansas	17.04	11.97
Louisiana	16.40	11.72

If these sums be multiplied by the acres per farm capita on cotton farms in 1926, an approximate idea is had of the net cash income per person on the farm from cotton. The following is such a calculation:

	Net cash returns per capita	
	To owners	To tenants
Alabama	$59.54	$47.41
Georgia	42.71	31.86
Mississippi	80.36	61.20
North Carolina	52.03	32.68
South Carolina	36.05	19.87
Texas	140.24	49.29
Oklahoma	149.51	88.85
Arkansas	85.20	59.85
Louisiana	60.68	43.36

Here again the efficiency of labor, as measured by the acreage grown, and soil fertility, as measured by the yield per acre, are the important factors controlling the net cash returns. Since 1926 was an unfavorable year in that yields did not in most cases make up for the loss in price, these figures may be taken only as relative between the states and not as indicating the success or failure of the cotton grower in a long-time program.

DIVERSIFICATION AND CROP ROTATION

Diversification of crops and rotation are believed to solve to a large extent the problems of soil fertility, economic returns to labor, and perhaps other difficulties. Unfortunately, we are unable to prove this by any scientific measurement based on facts. There are without doubt many farmers producing cotton on land unsuited to it and which are better suited to other forms of farming. We also have proof that cotton brings labor peaks which leave idleness at other periods and that these periods could be profitably employed in some additional lines of production. Propaganda for diversification

has been successfully employed to bring about reduction of cotton acreage at times when the season was ripe, but frequently the diversification has brought more loss and less money than cotton. This has been due to the absence of markets rather than the failure to produce successfully.

DISTRIBUTION

A discussion of cooperative marketing would no doubt be interesting, and perhaps it could be shown that the eastern cotton states have gone further with the new methods than the western states. However, with only five years of trial and with less than 10% of the crop included in cooperative selling, no real measurement of results is practicable. Those who have engaged in the processes are gratified, and many of them have gone into the second period. Theoretically, organized marketing, as well as organized buying, must be good business.

PROJECTING THE FUTURE

This discussion has clearly shown the existence of sharp competition between the eastern and western cotton-producing states. One would almost reach the conclusion that the development of production toward the West, if not checked, would soon push the East out of the game. That development, however, has had its setbacks. The acreage reduction this year was greatest proportionately in the western section. That section has its troubles. Unprofitable cattle gave way there to cotton. Will lack of profit some time swing the pendulum in the backward direction? Will the East find its solutions which will enable it to meet the competition of the West? Are there not competitions in each neighborhood which will tend to promote the survival of the fittest among neighbors and send the unsuccessful producers into other lines, either agricultural or industrial? Finally, will cotton consumption keep pace with increasing population and advancing civilization?

This last question is interesting and important. The last decade, not including 1926, saw a drop in production of cotton from 132,000,000 bales (1906 to 1915) to 117,000,000 (1916 to 1925). The consumption, domestic and foreign, of cotton took the same course, falling from 134,000,000 to 122,000,000 bales. During the last half of the past decade, however, consumption increased by 6,000,000 bales over the first half, while production was 1,500,000 bales less. The prediction was freely expressed that at least 3,000,000 bales of last year's crop would never be sold, but at the end of July consumption and exports had totaled 18,000,000 bales, 3,500,000 more

than the entire year previous leaving practically no added surplus. The World War seriously interfered with the movement of cotton toward world consumption. The nations are clearly recovering, and with their growth in needs and their ability to buy, who shall say if cotton will not be in demand for future expansion in the new lands of the West, while the East may still find it profitable to produce cotton if its economic problems are properly solved?

CONCLUSION

Among the seven problems we have mentioned as particularly affecting cotton production in the southeastern states, three lie in the field of agronomy. These are diversification and crop rotation, soil fertility, and the economic control of cotton pests. Experiment stations have accumulated a vast store of knowledge concerning soil fertility and perhaps the chief problem lies in taking it to the farmers in a convincing way, which is the province of the extension service. There is much to learn about diversification and the effects of rotation, and the information ought to be diligently sought and finally disseminated. Control of pests is supposed to be the province of the entomologists, but who can say if the agronomist has not yet something to do that will make that control economical and acceptable to the farmer?

In the field of farm management lies the problem of labor efficiency. Here, also, the extension service has obtained much basic knowledge which might be given to the farmer. It is one of the most far-reaching fields of possible development to the eastern cotton grower, and it should be one of the chief projects in every cotton county.

Of purely economic concern are the problems of distribution, production cost, and farm credits. We have yet much to learn of these subjects. They are of local importance, not only by states, but by counties and even by localities and individual farms. I do not hesitate to say that every cotton state, and especially those of the southeast, should dilligently apply considerable time and expense to their study and to the dissemination of information regarding them.

5. COTTON PRODUCTION METHODS IN THE SOUTHWEST[1]

A. B. CONNER[2]

The southwestern cotton-growing region produces annually more than 40% of the Nation's cotton crop. The methods used in the production of this crop, therefore, are of interest and importance to the entire Nation. A brief description of the region and its main features or characteristics will enable a better understanding of the methods in practice.

In general, that part of the cotton belt which can be properly designated as the Southwest has its eastern edge at the dividing line between the great black prairie region and the timbered section to the east. This line is approximately on the 96th meridian and includes roughly the western three-fourths of the states of Texas and Oklahoma and all of New Mexico and Arizona. East of this area, the general features of the territory are not radically different from those in the eastern part of the cotton-growing region of the South. Throughout the southwestern area the general climatic and soil conditions are radically different from eastern conditions, these differences becoming more marked as the western limits of cotton production are approached. While the cotton production methods outlined in this paper are applicable in a general way to the entire southwestern region, the discussion is based upon methods and practices now in use in Texas and other dry-land areas.

The climatic features of the Southwest embrace a more limited and more erratic rainfall than exists in the East and as one approaches the 97th meridian the rainfall decreases to 30 inches annually on the average and even lower to the westward. This region with less than 30 inches rainfall may be designated in general as the sub-humid region.

The temperatures of this region are moderate during the crop-growing season, owing to wind movement and the generally higher elevation than exists in the eastern cotton belt. The winter temperatures are somewhat lower than those of the eastern cotton-growing region because of the increasing altitude as one proceeds westward. In the extreme northwestern part of the sub-humid region, the altitude tends to shorten the crop-growing season. The weather of the growing season is characterized by bright warm days

[1]Paper read as part of the symposium on "Cotton" at the meeting of the Society held in Chicago, Ill., Nov. 17, 1927. Contribution from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Texas.

[2]Acting Director.

of intense sunlight with lower temperatures prevailing during the night and also a moderate wind movement throughout both day and night.

Generally speaking, the region constitutes smooth plains and prairies with increasing altitudes ranging from an elevation approaching sea level in the coastal plain to 4,000 feet in the high plains region of the Northwest.

The soils of the Southwest as outlined here lie within two main divisions. The soils of the humid prairie region consist largely of dark heavy calcareous friable clay types, while those of the sub-humid plains region consist largely of dark to reddish clay loams with clay subsoils and brown to reddish fine sandy loams with sandy clay subsoils. The sub-humid soils are usually productive and deep, have deep subsoils insuring a good reservoir for soil moisture, and are characterized by accumulations of lime carbonate, locally termed "caliche." It would seem that with good methods of farming the fertility of these soils could be maintained naturally for an indefinite period; in fact, comparing these soils with European soils of a similar character where farming has been practiced for centuries, it would seem that the question of soil fertility will not become a serious problem in the near future.

The environment of the Southwest generally is favorable to the production of what is known as "bread and butter" cotton of good grade and character. The extensive prairies and plains afford favorable conditions for the utilization of improved farm machinery in growing the crop. In the extreme northwest portion, the more limited stalk growth facilitates the use of economical harvesting methods. The extensive prairies and plains provide less opportunity for winter hibernation of insects and the higher and drier regions generally are unfavorable to constant depredations and losses from this cause and as well from fungous diseases. The sub-humid conditions existing over a large part of the region tend to discourage weed growth and afford favorable conditions for the easy control of weeds which is a factor of importance in effecting economies in the production of cotton.

Throughout the plains region, the cotton plant has shown a remarkable adaptability to growth and production under sub-humid conditions. The cotton plant assumes an altogether distinct habit of growth and otherwise adjusts itself to limited moisture conditions, producing a crop under rainfall conditions formerly considered less than necessary for crop production. This has led to the extension of cotton growing in the region westward where a few years ago

cotton production was considered impossible. Through the work of the experiment stations, cotton has been found to be even more able to resist or evade drouth than the grain sorghums which supply the region with a basic grain crop.

Cotton production methods in the Southwest may be divided for discussion into two phases: First, those methods having to do with the growing of the crop; and, second, those methods having to do with harvesting and preparing the crop for market.

The methods used in growing cotton in the Southwest seem to be centered around two big objectives recognized as important considerations in providing the proper conditions for the full development of the plant. These two objectives are (1) to provide the best conditions for the absorption of water by the soil, and (2) the use of systematic methods of weed control to prevent water losses. Experiment stations in Texas and elsewhere have shown conclusively the importance of storing water in the soil for the use of the succeeding crop, as well as the fact that the elimination of weed growth is the most important factor in the conservation of water stored in the soil.

The principal operations in growing cotton in the section include stalk disposal, preparation of the land, harrowing, planting, chopping, and cultivating.

The first step in growing the crop is to make proper disposal of the stalk growth. In the prairie region along the eastern part of the section designated as the Southwest, stalk disposal is considered as one of the necessary operations requiring the use of a stalk cutter and in some cases the uprooting of the plants. Uprooting of the plants is considered desirable in this region because it limits the food supply of the boll weevil and other insects and at the same time tends to minimize the carry-over of harmful plant diseases, such as cotton root rot. In the plains region, stalk disposal is relatively of little importance. Stalk cutting is sometimes resorted to but more often is entirely dispensed with, thus eliminating one of the operations which in other sections is considered as more or less necessary. So far as stalk disposal is concerned in the humid prairie region, cutters have been devised that reduce the man power requirement.

The second important step in growing the crop is the preparation of the land, either by plowing or "listing." "Listing" or bedding is perhaps the most common method of preparing the land throughout the region. This operation, if done by the use of horses, is usually accomplished with a one-row, four-horse lister or middle-buster. Two-row outfits pulled by horses are quite common in the plains

region. Tractor-drawn machines generally consist of two-row outfits. On the average, 5.5 acres can be "listed" or bedded in a 10-hour day by one man, according to studies made and published by the Texas Experiment Station, where a one-row, horse-drawn outfit is used, as compared to 15.9 acres where a two-row, tractor-drawn outfit is used.

Another important operation in connection with growing cotton in the Southwest is the harrowing of the land. In general this is practiced to a more limited extent than in some other sections, chiefly because it is coming to be recognized that following the preparation of the land it is desirable to leave it in an unpulverized condition so that the rough soil covering may provide a better receptacle for the absorption of water with a minimum loss by run-off. Harrowing is practiced chiefly as a means of killing weed growth and the harrow is considered as a very effective implement for this purpose if applied at the proper time. The operation of harrowing when done with a two-section, horse-drawn outfit enables one man to cover 21.7 acres per day, whereas with a four-section, tractor-drawn outfit one man can cover 43.5 acres in a 10-hour day. The use of four-section, horse-drawn outfits and six-section, tractor-drawn outfits is not uncommon, and thus the operation of harrowing as practiced is a cheap operation and a very effective means of destroying weed growth before planting time and as the first cultivation of the crop.

The next important step in growing the crop is planting which, in the Southwestern section, is done to some extent with single-row outfits. Two and four-row outfits are not uncommon and are quite generally accepted as being much more efficient. The acreage that can be planted in a 10-hour day by one man using a two-row, horse-drawn outfit has been found to be 14.3 acres, as compared to 35.7 acres where a four-row, tractor-drawn outfit is used.

The operation of chopping or thinning cotton is ordinarily accomplished in the prairie region of the Southwest in the same manner as in the East, but the operation of hoeing is perhaps not so common. In the prairie region of the Southwest, cross plowing and other operations have been tried out as a means of eliminating the necessity for thinning with a considerable degree of success. In the plains region the crop is quite generally planted at the desired seeding rate, thus dispensing with the operation of thinning requiring man labor.

In the operation of cultivating the crop four different methods have been studied by the Texas Experiment Station. It has been found that one man in a 10-hour day, using a two-row, horse-drawn outfit, can cover 15.4 acres as against 23.8 acres with a two-row.

tractor-drawn outfit; 43.5 acres with a four-row, tractor-drawn outfit; and 52.6 acres with a six-row, tractor-drawn outfit. No figures are available for a one-row, horse-drawn outfit but such an outfit would ordinarily cover about 8 acres a day.

The calculated cost of operating a set-up for a 200-acre cotton farm in the Corpus Christi, Texas, area, where animal power is used (more efficiently perhaps than in sections where single-row outfits are common) as compared to the cost of operating a similar sized farm in the same area where tractor power is used shows a saving of $851.50 in favor of the tractor set-up on the operations necessary in actually growing the crop exclusive of chopping. The greatest economy effected in this set-up is the great saving made in man labor which is reduced about half by the application of mechanical power.

It will be noted that in the growing of cotton in much of the Southwest certain operations which are considered as standard in other sections are of minor importance or do not enter into the cost of growing cotton. For example, the disposal of stalks preparatory to plowing the land is of little or no consequence. In fact, in a large part of the plains region, stalk cutting and other methods of stalk disposal are disregarded entirely since in much of this section the plants assume a characteristic dwarf growth which presents to the farmer no serious problem in stalk disposal. The chopping or thinning problem is not one of great concern in many sections as the best seeding rates are pretty well known. Also, since the cotton plant is able to adjust stands to a certain extent, growers oftentimes plant the crop so as to secure the stand desired and leave the difference to be adjusted by the plant itself, a practice entirely feasible in much of this territory.

Then there is the question of fertilizers, ordinarily required in much of the eastern cotton-growing region but of no concern at the present time to the cotton grower in the Southwest. This is true because the soils generally are virgin soils yet in a high state of fertility and experiments up to the present time have not shown that under the present conditions the use of fertilizers is warranted.

Still another problem of concern in the East is that of insects, necessitating systematic methods of poisoning. In a part of the prairie region poisoning for the boll weevil is resorted to but not practiced in the entire plains region. It is considered unnecessary for the reason that the natural conditions seem to hold the boll weevil and other insects under control. In fact, in a considerable portion of the southwestern cotton-growing region there is an entire absence

of boll weevils. This results in a considerable saving to the grower as compared to what would ordinarily be expended in the eastern region. These savings, together with the saving that can be accomplished through the use of improved machinery such as tractor outfits and outfits that enable one man to do the work of three or four men, have a tendency to give the cotton grower in the Southwest a material advantage over the grower in some other sections. This is a form of farm relief in that it tends to increase the production per man, reduce the cost per unit of production, and give the grower greater returns for his efforts.

The problem of harvesting cotton has in the past been a question largely dependent upon the cost of man power and, while many mechanical cotton pickers have been introduced, none of them to date have proved so satisfactory as to come into common use. Manufacturers heretofore have concerned themselves very largely with perfecting intricate movable machinery necessary to pick cotton and clean it in the field. Since the opening up of the new cotton region in the Southwest, the picking problem has become so acute and is attended with such labor conditions that the growers themselves have taken in hand the question of harvesting their cotton with limited amounts of labor. The first attempt along this line was in snapping cotton or pulling the open bolls by hand, thus enabling one man to gather increased amounts. Subsequently, mechanical strippers were devised that stripped the plant of bolls and portions of stems remaining on the plant at the time of stripping. The conditions in the region where stripping, or sledding as it is called, is practiced are almost ideal for such a process of harvesting. The plants are for the most part dwarf-like in stature and contain a large percentage of bolls to stalk. The cotton is usually not harvested until after frost and when the leaves have all fallen from the plant, leaving the small stalk with its full crop of open bolls in the best condition for stripping.

The first cotton harvested by these strippers or sleds was not considered by the ginners as acceptable for the reason that the gins were not equipped to extract the burs and clean the cotton. Subsequently, with this new demand made upon them, the gins, supported by the manufacturers, have devised and put into use equipment which handles sledded or stripped cotton, turning out middling grade cotton and better.

Sleds have played an important part in harvesting the crop of cotton in parts of the Southwest in times of labor shortages in the past and they will probably play a more important part in the

future, since there has been marked development and improvement in ginning and cleaning machinery. One finds in the Southwest gin plants with the most elaborate equipment to be found anywhere in the world, some plants being valued at from $50,000 to $60,000, whereas heretofore a gin with $25,000 worth of equipment was considered well equipped.

Contrary to the general opinion, sledding is not practiced generally in the entire Southwest. In fact, the conditions where sledding can be practiced to best advantage do not exist over the whole territory. It may be that at some time in the future sleds or strippers will be devised that can handle cotton under other growing conditions than those that exist where cotton is now sledded. However, this is not the case at the present time. Contrary to common opinion, sledding is not universally practiced even in a given section. It *is* practiced, however, as a last resort; and the development in this type of harvesting machinery and cleaning and ginning equipment seems to justify the belief that in time to come sledding will be universally practiced wherever the conditions are favorable for sledding.

Much remains to be done, however, in developing the sled and the gin machinery, but the progress already made has been far beyond the realization of the layman. Manufacturers are now concerning themselves with devising equipment that will separate the immature bollies from the mature bolls, and if such equipment is perfected, it will remove from the sledding practice the most objectionable feature at the present time, namely the presence of some immature bolls in the cotton. It seems to be generally recognized that cleaning machinery has already been developed and is now in operation that cleans cotton sufficiently that the trash contained is no longer objectionable to the spinners. It is probable that developments in the future will enable the gins and cleaning plants to sort out the immature bollies to be sold as immature cotton, leaving the mature cotton to be sold on the market as any other cotton is sold. Early-maturing defoliate cottons are particularly well adapted to sledding and the experiment stations have already made progress in developing such strains.

The picking cost of cotton is one of the heavy charges in the production of the crop. Records taken at random from 26 farms in Lubbock County, Texas, have shown that a crew of one man and two horses with a sled can harvest on the average 4.4 acres of cotton per day from which an average of 1.8 bales may be obtained. Allowing $3.00 per day for labor and $2.00 for the team the cotton was harvested at $1.13 per acre or $2.78 per bale. Cotton so harvested,

of course, requires an increased cost for ginning, but the saving is sufficient to justify the farmer in paying the ginner to do his part in cleaning the cotton, and this has been the stimulating factor behind recent marked advances made in ginning and cleaning equipment.

It is impossible to say what the future will bring in the way of developments in cotton growing and cotton harvesting methods, but it seems certain that the cotton production methods in the Southwest are efficient. Each year brings some new device or improvement in methods of cotton production, making more efficient the methods that are already comparatively efficient. Cotton growers in the older sections will do well to study these methods and lower their cost of production wherever possible.

NITROGENOUS FERTILIZERS AND SOIL ACIDITY: I. EFFECT OF VARIOUS NITROGENOUS FERTILIZERS ON SOIL REACTION[1]

W. H. PIERRE[2]

The rapid development in the manufacture of new nitrogenous fertilizers during the last few years has created considerable interest in their value. One of the important criteria in evaluating different nitrogenous fertilizers is their effect on soil reaction. It has long been known that the use of ammonium sulfate causes an increase in the acidity of the soil and that nitrate of soda, the other most commonly used inorganic source of nitrogen, has the opposite effect on soil reaction. Very little is known, however, regarding the effects of the various new nitrogenous fertilizers on soil reaction.

Among the most common of the new synthetic fertilizers are Leunasalpeter, urea, ammonium nitrate, and ammonium phosphate. Calcium nitrate and calcium cyanamid are two other synthetic fertilizers whose effects on soil acidity are not definitely known. Urea and ammonium nitrate have been reported by various investigators (2, 15)[3] as having no effect on the reaction of the soil. Brioux (5), on the other hand, has given experimental data indicating that the use of urea results in increased soil acidity. From a theoretical consideration it would seem that urea, ammonium nitrate, Leunasalpeter, ammonium chloride, and ammonium sulfate should all result in increasing the acidity of the soil, whereas calcium cyanamid, calcium nitrate, and sodium nitrate should have the opposite effect.

In view of the importance of this problem from the standpoint of practical agriculture, the present investigation was started.

The objects of the investigation were as follows:

1. To determine the effect of using these various nitrogenous fertilizers on the H-ion concentration of soils.

2. To determine the effect of using these fertilizers on the increase or decrease in the amount of hydrogen in the exchange complex of the soil.

[1]Paper presented at the meeting of the Southern Section of the Society held in Auburn, Alabama, Aug. 24–25, 1927. Contribution from the Department of Agronomy, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication Dec. 17, 1927.

[2]Associate Soil Chemist. The writer wishes to express his appreciation to Director M. J. Funchess and Dr. F. W. Parker for suggesting this problem and for the very helpful suggestions and criticisms rendered during the progress of the investigation.

[3]Reference by number is to "Literature Cited," p. 268.

3. To calculate from the data secured relative values that express the effect of these fertilizers on soil reaction and to compare these with values obtained from a theoretical consideration.

PLAN OF INVESTIGATION AND METHODS USED

Field and greenhouse investigations were started in the fall of 1925. The investigations reported in this paper consist of the greenhouse and laboratory study only. Most of the present work was done on two soils, a Norfolk sandy loam and a Cecil clay loam, secured from the plats of the two "Source of Nitrogen" experiment fields in Alabama.

Equivalent amounts of soil were weighed out into 2-gallon pots in the greenhouse and fertilized with equivalent amounts of superphosphate (acid phosphate) and muriate of potash at the rates of approximately 1,000 pounds and 100 pounds, respectively. The ammonium phosphate pots received no superphosphate (acid phosphate). Nitrogen was then added in the form of the various nitrogenous fertilizers in amounts equivalent to 1,110 and 1,430 pounds of ammonium sulfate per 2,000,000 pounds of soil for the Norfolk sandy loam and Cecil clay loam, respectively This fertilizer treatment was given to each crop except to the vetch crop which did not receive the nitrogenous fertilizers. Calcium nitrate, sodium nitrate, ammonium sulfate, ammonium nitrate, and urea were added as pure salts in solution form, whereas "cured ammonium sulfate," calcium cyanamid, and Leunasalpeter were added as the commercial product in solid form. Since all the sources of nitrogen added as pure salts except calcium nitrate are practically pure in the commercial form, their effects on acidity would be the same as if the commercial product were used. Calcium nitrate, however, sometimes comes on the market containing some ammonium nitrate. It was, therefore, thought best to use the pure salt rather than the mixture which sometimes varies in a commercial product.

The ammonium phosphate used was the commercial product analyzing 13% ammonia and 48% phosphoric acid. In adding equivalent amounts of nitrogen in the form of ammonium phosphate, it is evident that the ammonium phosphate pots received a greater amount of phosphorus than did the other pots which received their phosphorus in the form of superphosphate (acid phosphate). "Cured ammonium sulfate" is a commercial product that has been claimed to have no effect on soil acidity because of having been cured with superphosphate (acid phosphate). It contains 10% phosphoric acid and 6.6% ammonia. As in the case of ammonium phosphate, therefore, a greater amount of phosphorus was added in this

treatment than in the other treatments in order to get the required amount of nitrogen.

The first crop, oats, was planted in October 1925. Corn and sorghum were grown in succession during the summer and fall of 1926. Vetch was then grown during the winter and spring of 1926 to 1927. Due to high acidity and high salt concentration developed and consequent poor plant growth, only the first two crops were grown on the Norfolk sandy loam. Rain water was used in watering the pots during the experiment.

After the harvesting of each crop, the roots were removed from the pots, the soil was thoroughly mixed, and samples were taken for acidity studies. The crop yields obtained will not be reported in this paper. In general, all nitrogenous fertilizers gave approximately the same yields until in some cases an injurious acidity had been developed.

The acidity studies consisted of H-ion determinations and of determinations of exchangeable hydrogen. H-ion determinations were usually made on the soil samples previous to the planting of the succeeding crop by the dialysis-colorimetric method previously described (12). The determinations of exchangeable hydrogen were made by the barium acetate method of Parker (11). In a few cases the titration method was also used (11) The total exchange capacity was determined by a slight modification of Kelly's method (11). All treatments were represented by duplicate pots, and all the data presented represent averages of determinations from the duplicate pots.

EFFECT OF DIFFERENT NITROGENOUS FERTILIZERS ON SOIL REACTION

In studying the effect of different nitrogenous fertilizers on soil reaction, two kinds of studies should be considered, namely, studies of the H-ion concentration of the soil, and studies of the total amount of acidity developed. While the former is of greater importance in determining how soon injury to crops will result, the latter gives information, for example, on how much lime will have to be added to bring a soil fertilized with an acid-forming fertilizer back to its original reaction.

EFFECT ON H-ION CONCENTRATION

As previously explained, H-ion determinations were made on the soil from each pot after each crop was removed. The data in Table 1 represent the average of duplicate determinations. Considering first the Norfolk sandy loam, it will be noted that ammonium sulfate caused the greatest increase in H-ion concentration. Leunasalpeter,

ammonium phosphate, ammonium nitrate, and urea caused increased acidity in the order mentioned, whereas calcium cyanamid, calcium nitrate, and sodium nitrate caused a decrease. Of the three physiologically basic fertilizers calcium cyanamid caused the greatest decrease in acidity, while sodium nitrate and calcium nitrate both decreased the acidity but to a slightly less degree. The relative increases and decreases in H-ion concentration after the second crop are about in the same order. It will be noticed, however, that there has been no change in H-ion concentration by the second addition of ammonium sulfate. The probable reason for this is that, due to the low buffer capacity of this soil, such a high salt concentration and acidity had developed that nitrification could not go on, and therefore no additional acidity could be produced. For this reason it was not believed advisable to study this soil in much detail.

TABLE 1.—*The H-ion concentration of soils successively fertilized with different nitrogenous fertilizers.*

Source of nitrogen	H-ion concentration of soils after removal of crops					
	Norfolk sandy loam			Cecil clay loam		
	After oats pH	After corn pH	After oats pH	After corn pH	After sorghum pH	After vetch pH
None	5.35	5.50	6.05	6.06	6.00	6.03
None[a]	5.20	5.18	6.00	5.78	5.78	5.90
Sodium nitrate	5.60	6.25	6.25	6.60	6.78	6.60
Ammonium sulfate	4.45	4.43	5.30	5.00	4.63	4.80
Urea	5.15	5.00	5.80	5.65	5.43	5.45
Ammonium phosphate	5.00	4.60	5.70	5.20	5.18	5.20
Ammonium nitrate	5.10	4.95	5.80	5.55	5.45	5.48
Leunasalpeter	4.80	4.50	5.40	5.20	4.95	5.00
Cured ammonium sulfate	4.75	4.40	5.30	5.00	4.68	4.80
Calcium cyanamid	5.95	6.15	6.25	6.30	6.60	6.53
Calcium nitrate	5.60	5.75	6.00	6.25	6.38	6.30

[a]Received muriate of potash and superphosphate (acid phosphate) at the same rate as did the pots receiving nitrogenous fertilizers.

Considering the data from the Cecil clay loam (Table 1), it will be seen that the same relative order of acidifying power is maintained by the various acid-forming fertilizers. This soil has a greater buffer capacity, however, and the change in H-ion concentration from the use of fertilizers is less. Consequently, it was possible to grow four crops before a very high H-ion concentration was developed with some fertilizers. Sodium nitrate seems to have rendered the soil slightly more basic than did calcium cyanamid or calcium nitrate after the first crop. This is probably due to the fact that in the method of determining H-ion concentration the soil and water are allowed to remain in contact for 18 hours before the determination

is made, thus allowing the hydrolysis of the sodium compounds, which are present in large amounts, to go on more completely.

"Cured ammonium sulfate" had the same effect on the soil reaction as did the treatment in which ammonium sulfate and super-phosphate (acid phosphate) were added to the pots separately.

It is possible from the data obtained with the Cecil clay loam to make a more accurate numerical comparison of the acidity developed by the various acid-forming fertilizers. This was done by drawing a graph in which the amounts of ammonium sulfate added in succeeding crops were plotted against the resulting pH values obtained. The amounts of ammonium sulfate required to bring the soil to the same pH values obtained with the other acid-forming fertilizers after the third crop were then read from the graph and the relative acidifying powers compared. For example, after the third application of urea, the pH value of the soil was 5.43. From the graph it was found that it took 4.2 grams of ammonium sulfate per pot to give a pH value of 5.43. Thus, since 6.87 grams of urea had been required to develop this same pH value, it follows that it took 3.16 grams of nitrogen in the form of urea to produce the same H-ion concentration as was produced by 0.89 gram nitrogen in the form of ammonium sulfate. Thus, if the H-ion concentration developed by ammonium sulfate is taken as 100, the relative value for urea was found to be 28.1. Similarly, as is indicated in Table 2, the relative value for Leunasalpeter was found to be 65; for ammonium nitrate, 28; and for ammonium phosphate, 51.

It is known, however, that total salts affect H-ion concentration, and since in these pots the various treatments produced different amounts of total salts which, under the conditions of the experiment, could not leach out as would occur in the field, it was thought desirable to wash these soils and then compare the H-ion concentration developed by the various fertilizers. Thus, 10 grams of soil from each pot were leached in a Gooch crucible with five successive 10 cc portions of distilled water. The washed soil was then placed in a beaker, 50 cc of distilled water added, and the H-ion concentration determined by the electrometric method on the next day. By drawing a graph, as was done with the unwashed soil, the relative effects of the various fertilizers on the H-ion concentration of the soil were again calculated. The results are given in Table 2. It will be seen that the relative acidifying effects are then quite different.

The data given in the last column indicate one of the reasons for the differences. Thus, it is seen that the leachate of the ammonium sulfate treated soil had a lower resistance or a higher salt concen-

TABLE 2.—*Relative acidity developed by the acid-forming fertilizers as measured by the increase in the H-ion concentration of leached and unleached soils.*

Source of nitrogen	Relative acidity developed		Specific resistance of leachings at 24°C
	Unleached soil	Leached soil	*Ohms*
—	—	—	7,484
Ammonium sulfate	100	100	1,703
Leunasalpeter	65	83	2,371
Ammonium phosphate	51	75	7,113
Ammonium nitrate	28	50	2,841
Urea	28	53	4,150

tration than the leachate from the other treated soils. The higher salt concentration is largely due to the sulfate residue left in the soil. Thus, there was found 4.02 mgm of sulfur in the leachate of the ammonium sulfate treated soil and only 1.38 mgm in that of the ammonium nitrate treated soil. These large amounts of sulfate in the former indicate that there may be present small amounts of sulfuric acid in solution. Since sulfuric acid has a much higher degree of dissociation than soil acids, it is evident that the H-ion concentration of the cultures receiving ammonium sulfate would be higher and that of the other cultures receiving other sources of nitrogen would therefore be relatively lower under greenhouse conditions than after the soluble salts had been removed by leaching. Since under field conditions these salts are no doubt largely leached out of the soil, the data from the washed soil are believed to be a better measure of the relative acidifying effects of these various nitrogenous fertilizers.

EFFECT ON EXCHANGEABLE HYDROGEN

According to present theories if an acid is added to a soil, the hydrogen of the acid replaces some of the bases of the exchange complex. In order to be able to compare more definitely the relative effects of the various nitrogenous fertilizers on soil reaction, determinations of exchangeable hydrogen and of total exchange capacity were made on samples of the Cecil clay loam taken after the removal of the vetch crop.

The results are given in Table 3. It will be noted that the untreated soil contained 3.75 mgm equivalent of exchangeable hydrogen per 100 grams of soil and that all the fertilizers which caused an increase in H-ion concentration caused an increase in exchangeable hydrogen, while those that caused a decrease in H-ion concentration also caused a decrease in exchangeable hydrogen.

In the fourth column of Table 3 are given the relative increases or decreases in exchangeable hydrogen obtained by the barium acetate method. It will be noted that as compared with an increase

TABLE 3.—*The H-ion concentration, exchangeable hydrogen, and percentage saturation of Cecil clay loam treated with various nitrogenous fertilizers.*

Source of nitrogen	H-ion concentration	Exchangeable hydrogen: Barium acetate method		Titration method		Percentage saturation[b]
		Total	Relative	Total	Relative	
	pH	*mgm equiv*		*mgm equiv*		
None	6.03	3.75	—	3.26	—	54.8
None[a]	5.90	4.10	13	—	—	50.6
Sodium nitrate	6.60	2.60	—43	—	—	68.6
Ammonium sulfate	4.80	6.45	100	7.00	100.0	22.2
Urea	5.45	5.10	50	5.00	46.5	38.6
Ammonium phosphate	5.15	7.80	150	7.00	100.0	21.8
Ammonium nitrate	5.48	5.25	55	4.76	40.1	36.8
Leunasalpeter	5.00	5.80	76	6.00	73.5	30.1
Calcium cyanamid	6.54	2.25	—55	—	—	72.9
Calcium nitrate	6.30	2.70	—39	—	—	67.5

[a]Received superphosphate (acid phosphate) and muriate of potash at same rates as did pots receiving nitrogenous fertilizers.

[b]Calculated from data obtained by barium acetate method except in case of ammonium phosphate which figure was calculated from the results obtained by titration method.

in exchangeable hydrogen for ammonium sulfate taken as 100, the values for urea and ammonium nitrate are approximately 50, for Leunasalpeter 76, and for ammonium phosphate 150. On the other hand, the relative value for sodium nitrate was found to be —43; for calcium nitrate, —39; and for calcium cyanamid, —55.

The values calculated from the data obtained by the titration method are much the same with the exception that ammonium phosphate has a value of 100. This latter value, as will be seen later, is more in accordance with the theoretical value, and is believed to be more reliable for the following reason. The treatments of ammonium phosphate were such that a much higher amount of phosphorus was added than in any other treatment. As a result a much larger amount of phosphate is present in the soil. This is probably mostly present as iron and aluminum phosphates. In using the barium acetate method of determining exchangeable hydrogen, some of the iron and aluminum phosphates are believed to react with barium acetate with the formation of insoluble barium phosphate and iron and aluminum acetates. The iron and aluminum acetates, however, easily hydrolyze and form acetic acid. Thus, a greater amount of acid is actually titrated in the leachings than is found in the exchangeable form. In using the titration method of determining exchangeable hydrogen, the excess amounts of iron and aluminum phosphate present should have no effect and, therefore, the true value is believed to be more accurately indicated.

The total exchange capacity of the soil was not changed by fertilizer treatments except in the case of ammonium phosphate. Whereas the ammonium phosphate treated soil gave a total exchange capacity of 8.95 mgm equivalent, the soil from all other treatments had a total exchange capacity of 8.30 mgm equivalent. This high total exchange capacity of the former is no doubt due to the excessive amounts of phosphate applied in the form of ammonium phosphate. In the last column of the table is given the percentage of the total exchange complex that is combined with bases. The amount of bases in the exchange complex was obtained by subtracting the value for exchangeable hydrogen from the value for the total exchange capacity. It will be noted that the figures bring out in a striking manner the effect of the various nitrogenous fertilizers on the acidity of the exchange complex.

In Table 4 are given additional data on the exchangeable hydrogen of three other soils, one of which is the Norfolk sandy loam, some data for which were given in Table 1. It will be noted that about the same relative acidifying effects were obtained on these three soils for the various fertilizers as were found for Cecil clay loam reported in the previous table. Thus, if all the exchangeable hydrogen data from the four soils are considered, it is evident that urea and ammonium nitrate developed about the same acidity, or between 42 and 55% as much as ammonium sulfate. Likewise, Leunasalpeter developed between 68 and 76% as much, and ammonium phosphate about the same amount as ammonium sulfate.

TABLE 4.—*Total and relative amounts of exchangeable hydrogen of soils fertilized with various acid-forming nitrogenous fertilizers.*

Source of nitrogen[a]	Cecil clay		Norfolk sandy loam, I		Norfolk sandy loam, II	
	Total	Relative	Total	Relative	Total	Relative
	mgm equiv		*mgm equiv*		*mgm equiv*	
None	2.33	—	1.39	—	1.40	—
Ammonium sulfate. . .	3.23	100	1.90	100	1.85	100
Urea.	2.80	52	1.60	42	1.60	44
Ammonium phosphate. . .	—	—	—	—	1.87	104
Ammonium nitrate.	—	—	1.63	48	1.59	42
Leunasalpeter.	—	—	1.73	68	1.73	73

[a]The amounts of nitrogen added to each of the three soils were approximately equivalent to 1,000 pounds of ammonium sulfate per acre.

These values are in close agreement with the relative acidifying effects indicated by the hydrogen-ion concentration data of the washed soils given in Table 2. They are also in good agreement with

the relative amounts of lime necessary to correct the acidity formed. Thus in the accompanying paper (13) it is shown that the relative amounts of lime required are: ammonium sulfate, 100; ammonium phosphate, 83; Leunasalpeter, 77; urea, 51; and ammonium nitrate 47.

THEORIES REGARDING EFFECT OF NITROGENOUS FERTILIZERS ON SOIL ACIDITY

The effect of various nitrogenous and other fertilizer salts on soil reaction has been variously explained. Mayer, as is explained in detail by Kappen (9), was probably the first to advance a theory regarding their action. He classified fertilizers as being physiologically acid, physiologically alkaline, and physiologically neutral, depending on whether the plant absorbed the basic part, the acid part, or both parts of the salt in its nutrition. He believed that because plants utilized the potassium of potassium chloride and not the chlorine this salt was physiologically acid, since it left a residue of hydrochloric acid in the soil. On the other hand, sodium nitrate was considered physiologically basic, since the plant utilized the nitrate and not the sodium. These ideas of Mayer were substantiated to some extent by work with solution cultures, and some field experiments also pointed to the same conclusion.

Breazeale and LeClerc (4), working with wheat seedlings in solution cultures, found that the use of potassium chloride and potassium sulfate tended to leave the solution acid due to the absorption of the potassium by the plant with the consequent formation of hydrochloric and sulfuric acid, respectively.

Field work with sodium nitrate and ammonium sulfate tended to substantiate this viewpoint of Mayer, for these salts were found to decrease and increase the acidity of the soil, respectively. Hall (7) explained the effect of ammonium sulfate as follows, "The acidity of the soil where the ammonium salts have been used is due to the attack of various molds and other micro-fungi; they seize upon the nitrogen for their own nutrition and set free the acids with which the ammonia was combined."

Ruprecht and Morse (14) in explaining their results stated that the soil absorbs the ammonia, or that there is a double decomposition between ammonium sulfate and calcium carbonate, or some other salt, thus setting free sulfuric acid.

More recent investigations have led to the development of other variously modified theories regarding the effects of various fertilizers on soil acidity, especially with respect to ammonium sulfate. Thus, Frear (6) states as follows in regard to ammonium sulfate, "Its

continuous use inevitably tends to produce pronounced acidity in the soil. The reasons for this are not fully understood, although it is clear that it yields two acids, nitric and sulfuric, but no base, when nitrified."

As a result of the work at Rothamsted which showed that the addition of ammonium chloride and sulfate to a soil resulted in an almost immediate presence of chlorides and sulfates combined with calcium and magnesium in the drainage water, the new idea that two acids are formed from ammonium sulfate was expanded. Thus, it is described by Wheeler (16) that double decomposition occurs in this reaction, that ammonia is absorbed by the soil, that the sulfate radicle unites with the calcium and magnesium to be lost from the soil as such, thereby causing a loss of bases, and that a further loss of base occurs as a result of nitrification of the ammonia by which process the nitric acid formed unites with bases in the soil to be used up by the plants or lost through leaching as calcium or magnesium nitrates.

Ames and Schollenberger (1) first emphasized the fact that it is because of the nitrification process alone that ammonium sulfate causes soils to become acid. They state, "When a solution of potassium or ammonium salt (except the phosphate) is brought in contact with a soil, a considerable amount of the base is rapidly removed from solution and held by the soil while the acid is left in solution, free to attack any constituents of the soil which may be soluble. Although some carbonate may be lost in this way, the soil is really no poorer in bases than it was before, because whatever has been dissolved from the soil has been compensated for by the base entering the soil. In the case of ammonium sulfate, however, the absorbed base is capable of becoming acid through the process of nitrification, and a further amount of basic material will be removed from the soil."

This view has been expanded more fully by Page (10) who explained it according to the more recent ideas of base exchange. He emphasized the fact that nitrification is the cause of the acidity developed by ammonium sulfate and, furthermore, that it makes no difference in the acidity formed whether or not the calcium sulfate resulting from the base exchange reaction between the ammonium sulfate and the calcium complex leached out or remains in the soil. This view that nitrification rather than selective absorption of part of the fertilizer salt by the plant is the cause for the acidity developed by ammonium sulfate is further substantiated by experiments (3, 9) showing that approximately the same amounts

of acidity are developed whether or not plants are growing on the soil fertilized with ammonium sulfate. Page believes that the term physiological acidity, therefore, is not strictly correct, since the action is not caused by the plant but is strictly a chemical or biological process.

The present investigation makes possible a critical study of this theory as applied not only to ammonium sulfate but to other nitrogenous fertilizers as well.

PHYSIOLOGICALLY BASIC FERTILIZERS

As an example of physiologically basic fertilizer, sodium nitrate will be used in this discussion. The reason why sodium nitrate should leave a basic residue in the soil has never been thoroughly understood. Since it is a neutral salt it cannot decrease soil acidity, unless the plant exerts some effect. The basic action of sodium nitrate can be explained by making different assumptions. First, it can be assumed that the plant takes up the nitrate ion and leaves the basic sodium ion in the soil. This is the old conception of physiologically basic salts. Recent investigations (8) indicate, however, that plants probably absorb cations and anions in the same proportion or else that an exchange of ions occurs between the solution and the plant roots. If an exchange of ions occurs, the nitrate radicle might be taken up by the plants while the carbonate radicle would be given off. The amount of acids neutralized by sodium nitrate would then be determined by the extent to which the exchange of the nitrate for the carbonate radicle took place. If, on the other hand, the anions and cations are absorbed in the same proportion, the basic action of sodium nitrate can be assumed to be due either to the absorption of sodium nitrate and the giving off of sodium carbonate by the plant roots, or to the absorption of part of the nitrogen as nitric acid. The results reported in this paper can be explained by either of these assumptions. The latter, however, is the most simple and will be used in the following discussion, although the reactions are probably more complex than is thus indicated.

From the data presented in the accompanying paper (13) it can be calculated as to how much nitrogen would have to be taken up as nitric acid in order to account for the amount of soil acids neutralized by sodium nitrate. Thus it was found that 4 pounds of sodium nitrate were equivalent to 1.2 pounds of calcium carbonate in correcting the acidity of 1 pound of ammonium sulfate. This means that 2.40 mgm equivalent of calcium in calcium carbonate are equivalent

to 4.70 mgm equivalent of sodium in sodium nitrate. Evidently, then, only 51% of the nitrogen was taken up by the plant as nitric acid. If the plant had taken up all the nitrate as ions leaving the sodium as a residue, sodium nitrate should have neutralized twice the amount of acids that it did. The assumption, then, that the plant takes up the nitrogen of fertilizers partly as nitric acid is probably more satisfactory. As will be seen in the discussion of the acid-forming nitrogenous fertilizers, it also gives a probable explanation for the fact that the theoretical acidity from ammonium sulfate and other acid-forming nitrogenous fertilizers is not fully developed.

ACID-FORMING NITROGENOUS FERTILIZERS

The effect of acid-forming nitrogenous fertilizers on the soil can be most easily explained, as was done by Page for ammonium sulfate, by assuming that the ammonium salt added undergoes a base exchange reaction with the absorbing complex. The absorbing complex of the soil can be represented by the formula CaX, in which Ca represents the various exchangeable bases with which the insoluble anions, X, are combined in an exchangeable form. Let it be assumed for ease of discussion that the X can only combine with one Ca. When ammonium sulfate is added to a soil the following reactions take place:

1. $(NH_4)_2SO_4 + CaX \longrightarrow CaSO_4 + (NH_4)_2X$
2. $(NH_4)_2X + O_2 \xrightarrow{\text{nitrification}} 2HNO_3 + H_2X + 2H_2O$
3. $2HNO_3 + CaX \longrightarrow Ca(NO_3)_2 + H_2X$

As a result of the reaction represented in equation 1 it is evident that no acidity is developed. Moreover, it makes little difference whether or not $CaSO_4$ is leached out of the soil, for the calcium it contains has been replaced in the exchange complex by another base, ammonium. Until nitrification, represented in equation 2 goes on no acidity is developed. As a result of nitrification it is seen that two molecules of nitric acid and one molecule of dibasic soil acid are formed. The nitric acid may further react with another molecule of CaX forming $CaNO_3$, in which form the nitrate may be taken up by the plant, and another nolecule of H_2X formed. Thus, from one molecule of ammonium sulfate two molecules of a dibasic soil acid are eventually formed. These reactions are believed to represent quite accurately what takes place when ammonium sulfate is added to a soil, for it is well known that the absorption by the soil of the ammonia from ammonium sulfate is very rapid.

In order to neutralize the two molecules of dibasic acid formed from one molecule of ammonium sulfate, it is evident that it should take two molecules of calcium carbonate according to these equations. Thus, for every pound of ammonium sulfate it should take 1.5 pounds of calcium carbonate. It was found in the accompanying investigation, however, that only 1.2 pounds of calcium carbonate were necessary. The reason for a smaller amount of acidity being formed from ammonium sulfate than would be expected from a theoretical consideration is not entirely clear. It will be seen, however, that it could be explained by the same assumption that was made in explaining why sodium nitrate acts basic. Instead of the plant absorbing all its nitrates combined with a base as in calcium nitrate, it may absorb some as nitric acid. In explaining the basic effect of sodium nitrate, it was calculated that 51% of the nitrates were taken up as nitric acid. Assuming the same percentage in the case of the nitrates formed from ammonium sulfate, it should be possible to calculate what the theoretical acidity should be. Thus, only one molecule of the nitric acid represented in equation 2 would react further with CaX as in equation 3; and, only one-half a molecule of H_2X would be formed. Instead of requiring 1.5 pounds of lime per pound of ammonium sulfate to neutralize the acidity, it is evident that it should take only three-fourths that much, or 1.13 pounds. This value is in close agreement with the value of 1.2 pounds actually found.

In explaining the effects of ammonium nitrate similar equations can be used, for the reaction is much the same. The only difference in the reactions taking place would be shown in the first equation represented as follows:

1. $NH_4NO_3 + CaX \longrightarrow CaNO_3 + \frac{1}{2}(NH_4)_2X$

The $(NH_4)_2X$ then nitrifies as represented in the equations for ammonium sulfate, but since there is only one-half as much to nitrify only one-half the acidity will be developed. Since one molecule of ammonium nitrate contains the same amount of nitrogen as one molecule of ammonium sulfate, it follows that the former should only be one-half as acidic as the latter. This is in agreement with the relative acidifying effect found in this investigation.

Since Leunasalpeter is composed of one-half ammonium nitrate and one-half ammonium sulfate, the theoretical acidity formed should be about 75% of that of ammonium sulfate, a value that is in close agreement with that found.

With urea the reactions can be represented as follows:

1. $CO(NH_2)_2 \longrightarrow 2H_2O + (NH_4)_2CO_3$
2. $(NH_4)_2CO_3 + CaX \longrightarrow CaCO_3 + (NH_4)_2X$

Urea after being converted into ammonium carbonate undergoes a base exchange reaction with the soil as does ammonium sulfate and ammonium nitrate. The reactions following are then the same as with ammonium sulfate. It will be noted that the same amount of $(NH_4)_2X$ is formed as with ammonium sulfate, and, therefore, the same amount of acidity would be developed if it were not for the molecule of calcium carbonate also formed in the reaction which neutralizes one-half of the acidity formed. This explains why urea was found to develop only 50% of the acidity developed by ammonium sulfate.

The acidity formed by ammonium phosphate can also be explained by similar equations to that of ammonium sulfate. The only difference would be represented by a change in equation 1. Thus,

$$2NH_4H_2PO_4 + CaX \longrightarrow Ca(H_2PO_4)_2 + (NH_4)_2X$$

Mono-calcium phosphate is formed instead of calcium sulfate. Since the former, although an acid salt, is quite generally conceded to have no permanent effect on soil acidity, it is evident from the equation that for the same amounts of nitrogen in ammonium sulfate and ammonium phosphate the same amounts of $(NH_4)_2X$ and, therefore, the same amounts of acidity, should be formed. Thus, the theoretical acidifying effect of ammonium phosphate is in fair agreement with the value actually found in this study.

Under certain acid soil conditions, however, most of the phosphorus might unite with iron and aluminum oxides and calcium would be left free to neutralize some of the acids formed. It is possible, therefore, that under such conditions ammonium phosphate would not develop as much total acidity as ammonium sulfate, nor as much as the theoretical consideration would indicate.

SUMMARY

Studies were made regarding the effect of sodium nitrate, ammonium sulfate, urea, ammonium phosphate, ammonium nitrate, Leunasalpeter, calcium cyanamid, and calcium nitrate on soil reaction. Several different soils were treated in 2-gallon pots in the greenhouse with equivalent amounts of nitrogen in these fertilizers and grown to various crops in succession. The residual effects of these fertilizers on soil reaction were then determined by making studies of the H-ion concentration and the exchangeable hydrogen of the soils.

The H-ion concentration data showed that all the nitrogen fertilizers used caused some change in the H-ion concentration of the soils. Sodium nitrate, calcium nitrate, and calcium cyanamid were found to decrease the H-ion concentration. Ammonium sulfate caused the greatest increase in H-ion concentration and was followed in order by ammonium phosphate, Leunasalpeter, ammonium nitrate, and urea.

The relative increases in acidity from the use of the various acid-forming fertilizers as indicated by studies of H-ion concentration of the unleached soil were found to be as follows (Table 3): Ammonium sulfate, 100; ammonium phosphate, 51; Leunasalpeter, 65; urea, 28; and ammonium nitrate, 28. After the soils had been leached the relative values were as follows: Ammonium sulfate, 100; ammonium phosphate, 75; Leunasalpeter, 83; urea, 53; and ammonium nitrate, 50. Since the leached soils are believed to represent field conditions more accurately, the relative values obtained from studies on the washed soils are considered to be more reliable

The data obtained from the exchangeable hydrogen study made possible a more accurate comparison of the relative effects on soil acidity of the various nitrogenous fertilizers. The relative increases in exchangeable hydrogen from the use of the various fertilizers on different soils were found to be as follows: Ammonium sulfate, 100; sodium nitrate,—42; urea, 42 to 50; ammonium phosphate, 100 to 104; ammonium nitrate, 42 to 55; Leunasalpeter, 68 to 76; calcium cyanamid,—55; and calcium nitrate,—39.

The relative increases in exchangeable hydrogen from the various acid-forming fertilizers were found to be in good agreement with the relative increase in the H-ion concentration. These values were also found to be in close agreement with the theoretical amounts of acidity that should be developed. Thus, it was calculated from a theoretical consideration that the relative increases in soil acidity from the use of the various acid-forming fertilizers should be as follows: Ammonium sulfate, 100; ammonium phosphate, 100; Leunasalpeter, 75; urea, 50; and ammonium nitrate, 50.

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NITROGENOUS FERTILIZERS AND SOIL ACIDITY: II. THE USE OF FERTILIZER COMBINATIONS, LIME, AND BASIC SLAG IN CORRECTING THE ACIDITY FORMED BY VARIOUS NITROGENOUS FERTILIZERS[1]

W. H. PIERRE[2]

It has been shown in the accompanying paper (7)[3] that, besides ammonium sulfate, several of the new nitrogenous fertilizers cause soil acidity. Since these acid-forming fertilizers are gradually being used in greater amounts, it seems important to study methods by which the acidity which results from their use can be corrected, and to determine the amounts of materials that would have to be used. Various investigators (1, 3, 5) have reported work on the amounts of lime necessary to correct the acidity developed by ammonium sulfate, but no work has been published on the amounts necessary to correct the acidity formed by the new, acid-forming nitrogenous fertilizers. Besides liming, other methods appear practicable as means of correcting the acidity formed. These are, briefly, the uses of various fertilizer combinations in which the acids developed by the acid-forming fertilizer are neutralized by the basic action of other fertilizers used in the combination.

The objects of this investigation were as follows:

1. To determine the proportion in which various acid-forming and physiologically basic fertilizers can be used without changing the reaction of the soil.

2. To determine the amount of lime necessary to correct the acidity developed by various acid-forming fertilizers.

3. To determine the amount of basic slag necessary to correct the acidity formed by various acid-forming fertilizers.

The methods used in this study were similar to those employed in the first part of this investigation described in the preceding paper. The two studies were carried on simultaneously in the greenhouse and with the same soils, namely, a Cecil clay loam and a Norfolk sandy loam. The rate of fertilizing, the crops grown, and the methods used in determining the H-ion concentration and exchangeable

[1]Paper presented at the meeting of the Southern Section of the Society held in Auburn, Alabama, Aug. 24–25, 1927. Contribution from the Department of Agronomy, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication Dec. 17, 1927.

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[3]Reference by number is to "Literature Cited," p. 279.

hydrogen of the soils were likewise the same, except as will otherwise be stated.

COMBINATIONS OF PHYSIOLOGICALLY BASIC AND ACID-FORMING NITROGENOUS FERTILIZERS

Theoretically, it should be possible to combine various physiologically basic and acid-forming nitrogenous fertilizers in such relative amounts that they would have no effect on the acidity of the soil. In the accompanying investigation it was found that sodium nitrate, calcium nitrate, and calcium cyanamid decrease the acidity of the soil, whereas ammonium sulfate, ammonium phosphate, Leunasalpeter, urea, and ammonium nitrate cause an increase in soil acidity. The results presented in that paper also give the numerical increases or decreases in the exchangeable hydrogen of the Cecil clay loam caused by these fertilizers. From those data it is possible to calculate what proportions of various acid-forming and physiologically basic fertilizers it should be possible to use in combination so as not to change the reaction of the soil. Such calculations were made and the results are presented in Table 1.

TABLE 1.—*Proportions of various physiologically basic and acid-forming nitrogenous fertilizers required to maintain a soil at its original reaction.*[a]

Combination	Physiologically basic fertilizer Kind	Amount	Acid-forming fertilizers Kind	Amount
		%		%
1	Sodium nitrate	70	Ammonium sulfate	30
2	Sodium nitrate	54	Urea	46
3	Sodium nitrate	64	Leunasalpeter	36
4	Calcium cyanamid	65	Ammonium sulfate	35
5	Calcium cyanamid	52	Urea	48
6	Calcium cyanamid	58	Leunasalpeter	42

[a]Calculated from data given in Table 3 of preceding paper.

It will be seen that, according to the exchangeable hydrogen data secured, a combination in which 70% of the nitrogen is in the form of sodium nitrate and 30% in the form of ammonium sulfate can be used without affecting the reaction of the soil. If urea or Leunasalpeter are used instead of the ammonium sulfate, only 54 and 64% of the nitrogen, respectively, need be in the form of sodium nitrate. Since calcium nitrate has about the same action as sodium nitrate, it could be substituted for the latter. Similarly, in all these combinations ammonium nitrate could be substituted for urea and ammonium phosphate for ammonium sulfate in the same relative amounts. Combinations with calcium cyanamid as the source of the physiologically basic fertilizers are also given in Table 1. It will be seen that because its use results in a greater decrease in soil acidity

than the use of sodium nitrate, it can be used in combination with the various acid-forming fertilizers in slightly lower proportions than can sodium nitrate or calcium nitrate.

That the calculated values for the various combinations, as given in Table 1, are essentially correct is substantiated for the sodium nitrate-ammonium sulfate combination by the following experiment. The Cecil clay loam and Norfolk sandy loam soils in greenhouse pots were fertilized with various combinations of sodium nitrate and ammonium sulfate in which the relative amounts were varied, and cropped as has been described. After the removal of the second crop on the Norfolk soil and after the removal of the fourth crop with the Cecil soil, samples were taken from the pots for acidity studies. The results of the studies are given in Table 2.

TABLE 2.—*The H-ion concentration, exchangeable hydrogen, and percentage saturation of soils treated with different proportions of sodium nitrate and ammonium sulfate.*

Proportion of nitrogenous fertilizer		Cecil clay loam			Norfolk sandy loam
$NaNO_3$ %	$(NH_4)_2SO_4$ %	H-ion concentration pH	Exchangeable hydrogen *mgm equiv*[a]	Percentage saturation	H-ion concentration pH
—	—	6.03	3.75	55.1	5.50
100	0	6.60	2.60	69.0	6.25
80	20	6.10	3.45	58.8	5.50
60	40	5.70	4.40	47.4	5.05
40	60	5.28	5.20	37.8	4.78
20	80	4.98	6.00	28.2	4.48
0	100	4.80	6.45	22.8	4.43

[a]Milligram equivalents per 100 grams of soil.

It will be noted that with the Cecil clay loam the combination in which 80% of the nitrogen was added as sodium nitrate and 20% as ammonium sulfate resulted in decreasing the H-ion concentration and exchangeable hydrogen of the soil. On the other hand, if the proportion of nitrogen as sodium nitrate was decreased to 60% and that as ammonium sulfate increased to 40%, the H-ion concentration and exchangeable hydrogen of the soil were both materially increased. Thus, it is evident from these data that about 75% of the nitrogen of a sodium nitrate-ammonium sulfate combination should be added as sodium nitrate.

With the Norfolk sandy loam it was found that if the nitrogen present in the sodium nitrate-ammonium sulfate combination was in the ratio 80 to 20 the reaction of the soil was not changed. When this ratio of sodium nitrate to ammonium sulfate was increased the soil decreased in H-ion concentration, while if the ratio was decreased an

increase in the H-ion concentration resulted. Evidently, then, the use of a combination of sodium nitrate and ammonium sulfate in which about 75 to 80% of the nitrogen is present as the former and 25 to 20% as the latter has no effect on the reaction of the soil. This ratio is in fairly close agreement with the calculated proportions given in Table 1. It is safe to assume, then, that the calculated ratios given in Table 1 for the various other combinations of physiologically basic and acid-forming fertilizers are approximately correct.

AMOUNTS OF CALCIUM CARBONATE NECESSARY TO NEUTRALIZE THE ACIDITY DEVELOPED

Provided the total potential acidity is developed, it should take, theoretically, 1½ pounds of calcium carbonate to neutralize the acidity developed by 1 pound of ammonium sulfate. Various investigations have been reported regarding the amounts of lime it actually takes. Allison and Cook (1) concluded from a greenhouse study on four soils, to which were added ammonium sulfate, that it takes about 143 pounds of calcium carbonate, calculated from the calcium oxide used, to correct the acidity of 100 pounds of ammonium sulfate. Gardner, et al (5) concluded from a study of the old source of nitrogen plats at the Pennsylvania Experiment Station that, "The difference of about 1,000 pounds increase in the lime requirement between the smallest and largest application of sulfate of ammonia may be taken as a rough estimate of the effect of 48 pounds of nitrogen in this form on the acidity of the soil in five years." Since applications of fertilizers were added in alternate years, the total amount of nitrogen applied during this period was 120 pounds. This is equal to 600 pounds of ammonium sulfate. This means, then, that 1 pound of sulfate required 1.67 pounds of calcium carbonate. Considering the fact that the values obtained in these two investigations were calculated from determinations of lime requirement in which a factor had to be used, they check very well with the theoretical.

Hartwell and Damon (3) reported work on the source of nitrogen plats from the Rhode Island Experiment Station. They found that as an average for 34 years, 3 pounds more of calcium oxide were required per pound of nitrogen in the form of ammonium sulfate than the same amount applied in the form of nitrate of soda. This would mean 1.2 pounds of pure calcium carbonate per pound of ammonium sulfate. They conclude, however, that a slightly higher amount of lime would probably have been required had the extra lime been added so as to maintain the two plats at the same reaction during the whole period of the experiment.

The experiments to be reported were started at the same time as were the other experiments described. Ammonium sulfate was used as the source of nitrogen, and lime, in the form of precipitated calcium carbonate, was added in different amounts to different pots. The H-ion concentration and exchangeable hydrogen data are presented in Table 3.

It will be noted that with both soils about 1.2 pounds of precipitated carbonate were necessary per pound of ammonium sulfate to maintain the soil at its original pH value. The determinations of exchangeable hydrogen show the same result, as will be seen from the values given in columns three and four of Table 3. Similar experiments on five other soils likewise gave values between 1.2 and 1.3 pounds.

In order to determine the amounts of lime necessary to correct the acidity developed by the other acid-forming nitrogenous fertilizers, the following experiment was conducted with the Cecil clay loam soil which had been used in the accompanying study (7). Duplicate pots of the Cecil clay loam had been fertilized with equivalent amounts of the various acid-forming nitrogenous fertilizers. After

TABLE 3.—*The H-ion concentration and exchangeable hydrogen of soils fertilized with ammonium sulfate and various amounts of calcium carbonate.*

	Cecil clay loam			Norfolk sandy loam
Ratio between amounts of $(NH_4)_2SO_4$ and $CaCO_3$ applied	H-ion concentration	Exchangeable hydrogen	Lime necessary to neutralize acidity due to 1 pound of $(NH_4)_2SO_4$[a]	H-ion concentration
	pH	*mgm. equiv.*	*pounds*	pH
No treatment	6.03	3.75	—	5.35
1 to 0.0	4.80	6.45	—	4.43
1 to 0.5	5.15	5.35	1.2	5.03
1 to 1.0	5.83	4.20	1.2	5.23
1 to 1.5	6.40	2.65	1.1	5.50
1 to 2.0	6.90	1.40	1.1	6.00

[a]Calculated from data in preceding column.

the removal of the fourth crop the soils from the duplicate pots were thoroughly mixed together. Four separate 2,500-gram samples of the soil from each treatment were then placed in 1-gallon pots. In each case one of the 1-gallon pots was left unlimed, whereas the others were limed at various rates with precipitated calcium carbonate. The pots were then allowed to remain in the greenhouse uncropped, and were watered with rain water from time to time. After four months each pot was thoroughly mixed and samples of each taken for pH determinations. The amounts of lime added to each

series were then plotted against the pH values obtained, and the amounts of lime necessary to bring the soil of each series back to its original H-ion concentration interpolated. The relative amounts of lime necessary to bring the soils of the various series back to their original reaction were then calculated. Thus, it was found that if the value for ammonium sulfate is again taken as 100, the relative values for ammonium phosphate, Leunasalpeter, urea, and ammonium nitrate were 83, 77, 51, and 47, respectively. Thus, whereas 1 pound of ammonium sulfate required 1.2 pounds of calcium carbonate to neutralize its acidity, the same amount of nitrogen from the other acid-forming nitrogenous fertilizers required the following amounts: Ammonium phosphate, about 1.0 pound; Leunasalpeter, about 0.9 pound; ammonium nitrate and urea, about 0.6 pound.

COMBINATIONS OF BASIC SLAG AND AMMONIUM SULFATE

Since under field conditions a phosphatic fertilizer is usually used along with nitrogen and since basic slag is a source of phosphorus known to decrease soil acidity, it is obvious that by using ammonium sulfate or other acidic nitrogenous fertilizers with basic slag in certain proportions the soil could be maintained at its original reaction.

The question as to how much basic slag is necessary has never been studied. It is evident, however, that if the neutralizing value of basic slag were known as compared with lime this question could be answered from the results obtained in the accompanying study (7). Various investigators have compared the value of basic slag with that of ground limestone or lime in correcting soil acidity. Hartwell, et al (4) compared the value of different forms of basic slag with equivalent amounts of hydrated lime on the growth of Cos lettuce on an acid soil. They conclude that, "Based on this single comparison, * * * the calcium oxide in slags is about one-third as efficient for neutralizing purposes as when in hydrated lime." Since basic slag usually contains between 35 and 50% calcium oxide, this would mean that 1 pound calcium carbonate would be equal to 3.3 to 4.8 pounds of basic slag.

Bear and Gayle (2) compared Thomas slag phosphates and Duplex basic phosphate with ground limestone and calcium phosphate as to their effect in stimulating nitrification in an acid soil. The Duplex basic phosphate had a neutralizing value as compared with calcium carbonate of 46.63%, whereas the Thomas slag had a neutralizing value of 52.83% by laboratory tests. They applied the slags and limestone in such quantities as to supply equal neutralizing value, and conclude that, "Judging from the rate of nitrification it would

appear logical to conclude that either of the slags investigated has a value for use on acid soils equivalent to that indicated by its neutralizing power as measured by laboratory tests. On this basis, the equivalent in neutralizing value of 1 ton of high grade limestone can be obtained by the use of approximately 2 tons of either Thomas slag phosphate or Duplex basic phosphate."

Williams (10) reports even greater neutralizing value for basic slag. He compared the effect of basic slag with that of calcium carbonate and lime on the pH and replaceable calcium of soils. The slag was assumed to contain 40% calcium oxide and the liming materials were added on an equal calcium oxide basis. He found that the total amount of exchangeable calcium after the slag treatment was practically the same as with the calcium oxide or calcium carbonate treatment, but that the resulting H-ion concentration was slightly higher with the use of the basic slag. If the exchangeable calcium values are taken as a standard, these results indicate that basic slag is 71% as efficient as calcium carbonate, while if the H-ion data are considered as standard the relative value for basic slag would be somewhat lower.

It would thus seem from the results of these various investigations that basic slag has anywhere between 21 to 71 % as high a neutralizing value as pure limestone. This wide variation in values obtained is believed to be due largely to the different methods used in the experiments.

It seemed desirable, therefore, to determine directly the value of basic slag in correcting the acidity developed by the use of ammonium sulfate. The two soils used in this experiment were fertilized with various proportions of ammonium sulfate and basic slag. The basic slag used was the regular 100-mesh material containing 18% phosphoric acid. Determinations of H-ion concentration and exchangeable hydrogen were made as in the previous experiments. The data are presented in Table 4. It will be noticed that both the H-ion concentration and exchangeable hydrogen data show that it takes approximately 2 pounds of basic slag per pound of ammonium sulfate to maintain both the soils at their original reaction. This represents a ratio in which the phosphoric acid present as basic slag is lower in proportion to the ammonia used than is usually applied in fertilizer practice on many soils. Therefore, it is evident that for crops in which basic slag is equal to superphosphate (acid phosphate) as a source of phosphorus, it has a distinct advantage when used with ammonium sulfate, since it corrects the acidity developed by the latter. Likewise, it can be used with advantage with the other acid-

forming fertilizers. The amounts of basic slag necessary to correct the acidity of the other acid-forming nitrogenous fertilizers may easily be calculated from the data regarding the relative amounts of lime required which have been presented.

Comparing the value of basic slag with that of pure calcium carbonate, it will be seen that it is 60% as efficient as the latter in neutralizing the acids in the soil. This value is in close agreement with that secured by Bear and Gayle (2).

TABLE 4.—*The H-ion concentration and exchangeable hydrogen of soils treated with various proportions of ammonium sulfate and basic slag.*

Ratio between amounts of $(NH_4)_2SO_4$ and basic slag		Cecil clay loam			Norfolk sandy loam
$(NH_4)_2SO_4$	Basic slag	H-ion concentration pH	Exchangeable hydrogen *mgm equiv*	Basic slag necessary to correct acidity of 1 pound $(NH_4)_2SO_4$[a] *pounds*	H-ion concentration pH
-	—	6.03	3.75	—	5.35
1	1[b]	4.80	6.45	—	4.45
1	1	5.38	5.10	2.0	4.88
1	2	6.05	3.70	2.0	5.35
1	3	6.55	2.70	2.2	5.93
1	4	6.80	1.60	2.2	6.25

[a]Calculated from data in preceding column.

[b]Superphosphate (acid phosphate) substituted for basic slag.

GENERAL DISCUSSION

It is evident from this study that the acidity developed by the various acid-forming nitrogenous fertilizers can be corrected by three methods which can be used in a rational fertilizer practice.

The question may arise as to how the amounts of basic material recommended would apply under field conditions. It has been stated by various investigators that the soil type and crops grown must always be taken into consideration in drawing conclusions regarding the permanent effect of fertilizers on the reaction of field soils. From the data presented in this study and from the results of a previous investigation (8) with field soils, however, it is evident that the soil type and the crop grown have insignificant, if any, effects on the total amount of acids formed by acid-forming fertilizers. An exception to this fact might be found if the soil fertilized is so acid that nitrification does not take place or goes on only very slowly. In such a case the plant might take up some of its nitrogen in the form of ammonia and a smaller amount of acids would as a result be developed in the soil. The H-ion concentration at which nitrification is stopped, however, is, according to Waksman (9), about 4.4 to 4.8. Since this is a much higher H-ion concentration than is found for most field soils, it is believed that the soil type has little effect on the

total amount of acids developed by the various acid-forming fertilizers.

It must be remembered, however, that in regard to all three methods recommended for correcting the acidity developed no account is taken of the natural tendency of cropped soils to become acid. Therefore, the values given for amounts of calcium carbonate, basic slag, and physiologically basic fertilizers will only maintain the soil at a reaction similar to that which would be maintained if the soil had not received fertilizers. An amount of basic material equal to the total natural losses of bases from soils by cropping and leaching would be required in addition to the amounts recommended for correcting the acidity developed by fertilizers. Since there is a greater leaching of bases in open sandy soils than in heavier soils, it is evident that some soils will require greater amounts of basic material than others to maintain a given reaction. This explains why under certain field conditions a soil may gradually become more acid even when fertilized with sodium nitrate. In such cases the amount of bases leached from the surface soil and taken up by crops is greater than the total amount of base supplied by the sodium nitrate.

In applying to field practice the amounts of calcium carbonate recommended for neutralizing the acids developed by the various acid-forming fertilizers, it should also be remembered that the lime applied in these experiments was finely divided, precipitated calcium carbonate. If ordinary ground limestone is used, larger amounts would necessarily have to be applied, depending on the purity and fineness of division of the limestone. In experiments now in progress at the Alabama Experiment Station, it was found that it took twice as much ordinary ground limestone to bring acid soils to the same pH value after seven months' contact as it did precipitated carbonate. While the coarser particles of limestone no doubt gradually come into solution, it has never been definitely determined how long it takes for the various sized particles to react with the soil. It is evident from the work done at the Pennsylvania Experiment Station (6), however, that the coarse particles come into reaction very slowly. Therefore, ground limestone, containing considerable amounts of coarse material, should be used in larger amounts than is recommended for precipitated calcium carbonate.

SUMMARY

A study was made of three methods by which the acidity developed by various acid-forming nitrogenous fertilizers can be corrected. These methods are (a) the use of physiologically basic fertilizers, (b) the use of lime, and (c) the use of basic slag as the source of phosphorus. Two soils were used for the study, a Cecil clay loam and a Norfolk sandy loam. The soils were treated in pots in the

greenhouse, and the residual acidity developed was studied by making determinations of the H-ion concentration and exchangeable hydrogen of the variously treated soils.

It was found that the use of a combination of sodium nitrate and ammonium sulfate in which the proportion of nitrogen in the two fertilizers is in the ratio of 75 to 25 leaves the two soils at their original reaction. This proportion agrees well with the values that can be calculated from a consideration of the separate effect of these fertilizers on the exchangeable hydrogen of the soil. The calculated proportions in which other physiologically basic and acid-forming fertilizers can be used without affecting the reaction of the soil were also given.

The acidity developed by the use of 1 pound of ammonium sulfate was found to be corrected by the use of 1.2 pounds of precipitated calcium carbonate. An equivalent amount of nitrogen in the form of ammonium phosphate, Leunasalpeter, urea, and ammonium nitrate required 1.0, 0.9, 0.6, and 0.6 pounds of precipitated calcium carbonate, respectively.

It was found that 1 pound of ammonium sulfate requires about 2.2 pounds of basic slag to correct the acidity formed. Since this represents a proportion of nitrogen to phosphorus smaller than is often used in fertilizer practice, it is evident that the use of basic slag as the source of phosphorus is a practical way of correcting the acidity developed by acid-forming nitrogenous fertilizers.

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INFLUENCE OF VARIOUS NITROGENOUS FERTILIZERS ON AVAILABILITY OF PHOSPHATE[1]

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The availability of phosphate in a soil is influenced to a marked degree by the acidity of the soil. Parker and Tidmore (12)[3] have shown that liming increases the solubility of phosphate in soils receiving superphosphate (acid phosphate) and basic slag. Spurway (17) has shown that the solubility of soil phosphorus is also influenced by the nature of the exchangeable base in the exchange complex of the soil. Pierre (14) and other workers have shown that different nitrogenous fertilizers influence the reaction of the soil and the base saturation of the exchange complex. It seems probable, therefore, that the source of nitrogen would influence the availability of the phosphate of the soil.

The purpose of this investigation was to study the availability of the phosphate in plats of the long-continued sources of nitrogen experiments of the Alabama, Rhode Island, and New Jersey Experiment Stations in order to compare the effect of different sources of nitrogen.

METHODS

Phosphorus availability was studied by determining the solubility as indicated by the phosphate concentration of displaced solution, 1:5 water extracts, and 1:5 carbonic acid extracts. The availability in the plats from the New Jersey Experiment Station was also studied by determining the amount of phosphate removed from the soil by continued leaching, the amount absorbed from a solution of monopotassium phosphate, and the amount removed from the soil by wheat seedlings, using Neubauer's method (8).

In obtaining the displaced solutions, the soils were brought to the desired moisture content, thoroughly mixed, and allowed to stand 48 hours. At the end of that period the soil solutions were dis-

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[3]Reference by number is to "Literature Cited," p. 292.

placed, using the procedure described by Burd and Martin (2).

Water extracts and carbonic acid extracts were obtained by the use of collodion sacks, according to the procedure described by Pierre and Parker (15).

Organic and inorganic phosphates were determined by the coeruleomolybdate method of Deniges (3) as modified for use in this type of work by Parker and Fudge (11). Pierre and Parker (16) have shown that organic phosphate, as such, is not available in the phosphorus nutrition of the plant. Its determination, however, is of value since it furnishes an indication of the amount of soluble organic phosphorus compounds subject to mineralization by micro-biological activity.

EXPERIMENTAL RESULTS

ALABAMA EXPERIMENT STATION PLATS

The sources of nitrogen plats at the Alabama Experiment Station have been described in detail by Pierre (13). They were started in 1911 with the purpose of comparing sodium nitrate, ammonium sulfate, and calcium cyanamid. All plats received fertilizer at the rate of 160 pounds superphosphate (acid phosphate), 100 pounds kainit, and 150 pounds sodium nitrate or its nitrogen equivalent per acre to each crop. Two crops have been grown each year. Since 1925, only one crop has been fertilized, plats 1 to 4 receiving their fertilizer in the fall for the winter crop of oats and plats 5 to 8 in the spring for the miscellaneous summer crops. Samples of the plats were collected in January, 1927. The data secured in the study of these plats are presented in Table 1.

The results obtained show that ammonium sulfate has increased the acidity of the soil from pH 5.45 in plat 3 to 4.55 in plat 4. This increased acidity is accompanied by a decrease in the solubility of inorganic phosphate. The differences in phosphate concentration of the displaced solutions are not significant, but the results obtained with both water and carbonic acid extracts indicate a marked reduction in phosphate solubility due to the use of ammonium sulfate. Thus, the check plat contained 2.3 p.p.m. water-soluble inorganic phosphate, while plat 4, receiving ammonium sulfate, contained but 1.1 p.p.m.

Sodium nitrate has not materially influenced the acidity and all results show that the solubility of phosphate is about the same as that of the check plat. Calcium cyanamid has decreased the acidity of the soil from pH 5.45 to pH 5.85, and markedly increased inorganic phosphate solubility. Thus, the water extract of plat 3 contained 2.3 p.p.m. inorganic phosphate, while plat 2 contained 4.4 p.p.m., an

increase of 91%. The concentration of organic phosphate is somewhat lower in the water extract of this plat than in extracts from other plats. The total amount of soluble phosphate, however, is higher than in any other plat.

TABLE 1.—*Influence of source of nitrogen on phosphate concentration of displaced solutions, water extracts, and carbonic acid extracts of the Alabama Experiment Station plats.*

			Phosphate concentration in p. p. m.						
Plat No.	Source of nitrogen	pH	Displaced solution[a]			1:5 water extract[b]			1:5 H_2CO_3 extract[b]
			Inorganic	Organic	Total	Inorganic	Organic	Total	Inorganic
1	$NaNO_3$	5.60	0.08	0.48	0.56	2.5	4.4	6.9	3.51
2	$CaCN_2$	5.85	0.05	0.46	0.51	4.4	2.9	7.3	5.20
3	Check	5.45	0.05	0.40	0.45	2.3	3.2	5.5	3.04
4	$(NH_4)_2SO_4$	4.55	0.06	0.31	0.37	1.1	3.8	4.9	1.94
5	$NaNO_3$	5.25	0.07	0.46	0.53	2.8	2.6	5.4	1.52
6	$CaCN_2$	5.40	0.07	0.41	0.48	4.8	1.6	6.4	2.48
7	Check	5.20	0.07	0.30	0.37	2.5	2.0	4.5	1.08
8	$(NH_4)_2SO_4$	4.60	0.04	0.34	0.38	1.1	2.3	3.4	1.00

[a]Based on displaced solution.
[b]Based on air-dry soil.

Attention should be called to the fact that in these plats and those of the other stations to be reported later, crop yield differences on the various plats have been very great for many years. In most cases, where lime has not been added, ammonium sulfate has caused a marked decrease in yield, as compared with the check plat, while physiologically basic fertilizers have caused large increases. Consequently, there has been a much more efficient use of phosphatic fertilizer and a heavier drain on the available phosphates of the soils of the latter plats.

RHODE ISLAND EXPERIMENT STATION PLATS

The source of nitrogen experiment of the Rhode Island Experiment Station was started in 1893 on a Merrimac silt loam and has been described in detail in various bulletins and annual reports of that station. The liming history to date is given in detail by Hartwell and Damon (4). All plats received the same amounts of nitrogen, but plats 23 and 25 received ammonium sulfate and plats 27 and 29 received sodium nitrate. Up to 1915, plats 23 and 27 had received no lime, but by that year plat 23 had developed such an acidity that liming was necessary in order to permit plant growth. Since that time 4,000 pounds of calcium oxide per acre have been applied. The corresponding plat 27 has never received any lime. Plats 25 and 29 have received lime since the experiment started, but in different amounts since 1914. Plat 25 has received 8,000 pounds of calcium

oxide per acre, while plat 29 received but 3,000 pounds. No regular rotation has been practiced on the plats. Superphosphate (acid phosphate) and muriate or sulfate of potash have been added as necessary, the annual application averaging 112 pounds phosphoric acid and 105 pounds potash per acre. All plats have always received the same amounts of phosphoric acid and also of potash. Samples were collected in the spring of 1926, two weeks after the application of 110 pounds phosphoric acid, 100 pounds potash, and 1,500 pounds of calcium oxide per acre, and shipped to Auburn. The results obtained with samples from these plats are presented in Table 2.

In spite of the relatively large amounts of lime added to plat 23, it still shows a very strongly acid reaction, pH 4.80, as compared with the unlimed nitrate plat which has a reaction of pH 5.35. Plats 25 and 29 are weakly acid with reactions of about pH 6.1.

Although in most cases the differences in phosphate solubility are quite small, the plats receiving nitrate of soda have given higher results than plats receiving ammonium sulfate. Thus, the carbonic acid extract of plat 29 gave 0.84 p.p.m. PO_4, as compared with 0.68 p.p.m. PO_4 on plat 25, although the two soils have the same reaction. Liming has slightly increased phosphate solubility on plats receiving both sources of nitrogen.

NEW JERSEY EXPERIMENT STATION PLATS

Displaced solutions and water extract method.—The sources of nitrogen plats at the New Jersey Experiment Station were started in 1908. The details of the fertilizer treatment are given in various publications from that station (1, 5, 6, 7). Until 1922 the fertilizer treatment had been at the rate of 640 pounds superphosphate (acid phosphate), 320 pounds muriate of potash, and 320 pounds sodium nitrate or its nitrogen equivalent per acre. In 1922 and succeeding

TABLE 2.—*Influence of source of nitrogen on phosphate concentration of displaced solutions, water extracts, and carbonic acid extracts of the Rhode Island Experiment Station plats.*

Plat No.	Source of nitrogen	pH	Phosphate concentration in p. p. m.						
			Displaced solutions[a]			1:5 water extracts[b]			1:5 H_2CO_3 extracts[b]
			Inorganic	Organic	Total	Inorganic	Organic	Total	Inorganic
23	$(NH_4)_2SO_4$	4.80	0.34	0.20	0.54	0.32	0.60	0.92	0.63
25	$(NH_4)_2SO_4$, lime	6.10	0.50	0.09	0.59	0.36	0.52	0.88	0.68
27	$NaNO_3$	5.35	0.40	0.13	0.53	0.38	0.94	1.32	0.72
29	$NaNO_3$, lime	6.15	0.52	0.11	0.63	0.56	0.72	1.28	0.84

[a]Based on displaced solution.

[b]Based on air-dried soil.

years minerals were reduced to 320 pounds of superphosphate (acid phosphate) and 160 pounds muriate per acre. Dried blood was discontinued in 1922 and nothing substituted for it. Samples of the plats were taken in the spring of 1926. Table 3 gives the results obtained in the study of the displaced solutions and water and carbonic acid extracts.

Ammonium sulfate increased acidity from pH 4.85, the reaction of the check plat, to pH 4.25. All other sources of nitrogen except dried blood have decreased the acidity, the largest change being in plat 12A, receiving calcium cyanamid, with a reaction of pH 5.35. Liming greatly decreased the acidity on all plats. Plats 13B and 11B, receiving dried blood and ammonium sulfate, respectively, have pH values significantly lower, however, than the other plats.

On the unlimed plats, sodium nitrate decreased acidity from pH 4.85 to pH 5.20 and gave more soluble inorganic phosphate than any other source of nitrogen. At the same time, ammonium sulfate, increasing acidity from pH 4.85 to pH 4.25, has caused a marked decrease in phosphate solubility. Thus, the water extracts of plat

TABLE 3.—*Influence of source of nitrogen on phosphate concentration of displaced solutions, water extracts, and carbonic acid extracts of the New Jersey Experiment Station plats.*

Plat No.	Source of nitrogen	pH	Phosphate concentration in p. p. m. Displaced solutions[a] Inorganic	Organic	Total	1:5 water extracts[b] Inorganic	Organic	Total	1:5 H_2CO_3 extract[b] Inorganic
			Unlimed Sections						
4A	Minerals only	4.85	0.14	0.48	0.62	0.24	0.33	1.45	0.8
7A	No fertilizer	4.60	0.10	0.03	0.13	1.12	0.29	0.53	0.9
8A	½ $NaNO_3$	5.25	0.16	0.15	0.31	2.35	0.55	2.90	2.9
9A	$NaNO_3$	5.20	0.23	0.17	0.40	3.30	0.65	3.95	4.8
10A	$Ca(NO_3)_2$	5.15	0.17	0.02	0.19	2.65	0.15	2.80	1.9
11A	$(NH_4)_2SO_4$	4.25	0.07	0.29	0.36	0.40	0.27	0.67	0.8
12A	$CaCN_2$	5.35	0.14	0.07	0.21	2.63	0.27	2.90	2.6
13A	Dried blood	4.75	0.25	0.06	0.31	0.72	1.13	1.85	2.2
			Limed Sections						
4B	Minerals only	6.45	0.40	0.14	0.54	10.00	0.35	10.35	12.8
7B	No fertilizer	6.35	1.00	0.44	1.44	8.45	0.25	8.70	13.5
8B	½ $NaNO_3$	6.35	0.60	0.24	0.84	7.90	0.20	8.10	10.4
9B	$NaNO_3$	6.55	0.62	0.26	0.88	10.40	0.25	10.65	16.1
10B	$Ca(NO_3)_2$	6.50	0.56	0.24	0.80	7.40	0.10	7.50	13.9
11B	$(NH_4)_2SO_4$	6.20	2.10	0.20	2.30	19.15	0.85	20.00	23.8
12B	$CaCN_2$	6.35	0.56	0.44	1.00	3.85	0.15	4.00	9.8
13B	Dried blood	6.05	1.08	0.34	1.42	1.12	0.45	1.57	1.6

[a]Based on displaced solution.

[b]Based on air-dried soil.

9A, receiving sodium nitrate, contained over eight times as much inorganic phosphate as the extract of plat 11A, receiving ammonium sulfate. All other physiologically basic nitrogenous fertilizers and dried blood gave phosphate solubilities intermediate between these two sources. Ammonium sulfate is the only source of nitrogen which has noticeably increased acidity, and is the only one which has not increased phosphate solubility when compared with the check plat, 4A.

Liming greatly reduced acidity on all plats and increased phosphate solubility on all plats except 13B. The greatest change was on plat 11B, receiving ammonium sulfate. The liming of this plat reduced acidity from pH 4.25 to pH 6.20, and increased the water soluble inorganic phosphate from 0.4 p.p.m. to 19.2 p.p.m. It also resulted in large increases in the phosphate concentrations of the displaced solution and carbonic acid extract. With the exception of plat 11B, plat 9B, receiving sodium nitrate, gave the highest phosphate solubility. Liming has so greatly increased phosphate availability that the addition of a basic nitrogenous fertilizer had no appreciable effect.

Leaching method.—Studies on displaced solutions and water extracts do not indicate the ability of the soil to maintain a given concentration over a considerable period during which the element is being removed by the plant. Parker (10) has shown that in the phosphorus nutrition of the plant the concentration of phosphate beyond a very low figure is by no means as important as is the maintenance of that concentration. In order to secure a better indication of the ability of the soil to maintain a given concentration of phosphate, the following experiment was conducted.

Ten grams of soil were placed in a 25-cc Gooch crucible and leached with 300 cc of water. The water was added in 10-cc portions, each

TABLE 4.—*Influence of source of nitrogen on phosphate availability, as shown by continued leaching of New Jersey soils.*

Plat No.	Source of nitrogen	First 50 cc[a]		Fourth 50 cc[a]		Total[a]	
		Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
		p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
4	Minerals only	4.9	18.4	2.4	8.3	20.0	70.7
7	No fertilizer	1.0	22.9	0.6	11.4	3.9	89.4
8	½ $NaNO_3$	12.0	28.2	7.2	10.3	54.3	95.3
9	$NaNO_3$	15.6	33.8	12.9	18.6	79.6	130.8
10	$Ca(NO_3)_2$	11.5	20.0	6.3	12.3	46.5	83.6
11	$(NH_4)_2SO_4$	0.9	55.0	1.4	20.3	7.3	168.8
12	$CaCN_2$	12.1	13.9	6.4	8.6	46.2	58.4
13	Dried blood	11.1	2.5	5.7	1.1	45.9	9.3

[a]Based on air-dry soil.

portion being drawn through by suction before the next portion was added. The leachate was collected in six successive 50-cc portions and analyzed for inorganic phosphate. The data secured in the work are given in Table 4.

The phosphate content of the first 50-cc portion was quite high, but diminished in the second and third portions. The fourth, fifth, and sixth portions were practically the same, and the concentration may be taken to represent the equilibrium point of each soil under the conditions of the experiment.

The sodium nitrate plat gave the highest initial concentrations of phosphate on the unlimed sections, followed by plats receiving calcium cyanamid, one-half sodium nitrate, calcium nitrate, and dried blood, the latter four treatments being practically equal in their effect on phosphate solubility. Plats receiving minerals alone, no fertilizer, and ammonium sulfate gave very low concentrations. On the limed sections the ammonium sulfate plat gave the highest concentration, followed by the sodium nitrate plat. With the exception of the calcium cyanamid and the dried blood plats, which were comparatively quite low, all other plats gave practically the same concentration. Liming greatly increased the solubility of phosphate, but the relative increase due to liming was dependent upon the source of nitrogen. Ammonium sulfate gave an increase of over 6,000 %, sodium nitrate an increase of 116 %, calcium cyanamid an increase of 15%, and dried blood a decrease of 78%. An interesting comparison of this method and the regular 1:5 water extract is given by comparing the phosphate concentrations of the first 50-cc portion with those of the 1:5 water extracts given in Table 2. For example, plat 9A in this method gave 15.6 p.p.m. PO_4, while the same soil in the 1:5 water extract gave only 3.3 p.p.m. PO_4. The ratio of soil to water is the same in both methods, the difference probably being due to the removal by the leaching method of the soluble compounds which depress the solubility of the phosphates.

The relative order of the phosphate solubility of the different plats is essentially the same in the fourth 50-cc portion as in the first 50 cc, altho the differences in phosphate concentration are much smaller. The effect of liming is still evident, but the difference between limed and unlimed sections is smaller, indicating that a large amount, but by no means all, of the additional available phosphate in the limed sections is tied up in easily soluble compounds.

The figures given in the last two columns of Table 4 represent the total amount of phosphate removed by the 300 cc of water. As is to be expected, the same order of phosphate differences was main-

tained. The sodium nitrate plat contained considerably more soluble phosphate than any other plat, and was second only to the ammonium sulfate plat on the limed sections. All sources of nitrogen, with the single exception of ammonium sulfate, increased the amount of soluble phosphates in the unlimed sections. Sodium nitrate quadrupled and other sources more than doubled the amount of soluble phosphate when compared with the check. The increase in soluble phosphates due to the nitrogenous fertilizer was not so marked on the limed plats but was significant in all cases except with calcium cyanamid and dried blood which have caused decreases.

The experiment has shown again very clearly that sodium nitrate gave the greatest amount of soluble phosphate and ammonium sulfate the least when lime was not used to correct acidity and supply bases. When lime was used, the ammonium sulfate plat contained the largest amount of soluble phosphate followed by the sodium nitrate plat.

Phosphate absorption method.—The work on continued leaching indicated large differences in the solubility of phosphate in the different soils. The question arose as to whether the amount of phosphate necessary to satisfy the phosphate absorptive capacity of the soils might not also vary widely. In order to study this question, the following experiment was conducted.

Ten grams of soil were shaken with 500 cc of a solution of monopotassium phosphate, containing 100 p.p.m. of PO_4, until equilibrium had been established between the soil and the solution. The concentration of phosphate in the solution was then determined and the amount of phosphate absorbed by the soil calculated. Table 5 gives the results of this experiment.

On the unlimed sections, the plats receiving nitrate of soda gave the least absorption. The absorption was slightly greater in plats receiving minerals only and minerals and dried blood, while the plat which received ammonium sulfate absorbed 50% more than the plats receiving nitrate of soda. Liming materially decreased absorption, and there were no very significant differences on these sections.

Neubauer seedling method.—The preceding methods have shown, by strictly chemical methods, significant differences in solubility of phosphates due to different nitrogenous fertilizers. The question arose as to whether these differences would be reflected as strongly in the utilization of the phosphate by plants grown in the soils. Neubauer and Schneider (8) have proposed a method by which this question may be answered. The method is based on the consideration that if a large number of seedlings are grown in a small amount

of soil, the amount of phosphorus and potassium absorbed will indicate the availability of these two elements. In this method 100 rye seedlings are grown in a mixture of 100 grams of soil and 50 grams of sand covered with 250 grams of sand. After 17 days, the seedlings are washed out of the soil and the entire plants analyzed for phosphorus and also for potassium, if the latter is desired.

Various workers have proposed modifications of the method, but after preliminary work, it was decided to use the regular procedure, with the single exception that instead of using rye seed, wheat seed was used. This change was made necessary because of the fact that it was impossible to get heavy rye seed of high germination suitable for this work. While the absolute amount of phosphorus and potassium taken up by wheat seedlings may be different than that taken up by rye seedlings, differences in the availability of the phosphate of the soils due to differences in sources of nitrogen will be reflected by wheat seedlings as well as by rye seedlings. Table 6 presents the data secured in this work.

TABLE 5.—*Influence of source of nitrogen on absorption of phosphate by New Jersey soils.*

Plat No.	Source of nitrogen	PO_4 in solution in p.p.m. Unlimed Start	End	Absorbed	Limed Start	End	Absorbed	PO_4 absorbed by air-dry soil in p.p.m. Unlimed	Limed
4	Minerals only	100	76.5	23.5	100	88.5	11.5	1,175	575
7	No fertilizer	100	76.5	23.5	100	84.0	16.0	1,175	800
8	½ $NaNO_3$	100	80.0	20.0	100	88.0	12.0	1,000	600
9	$NaNO_3$	100	79.0	21.0	100	86.5	13.5	1,050	675
10	$Ca(NO_3)_2$	100	79.0	21.0	100	87.5	12.5	1,050	625
11	$(NH_4)_2SO_4$	100	69.0	31.0	100	85.0	15.0	1,550	750
12	$CaCN_2$	100	78.5	21.5	100	85.0	15.0	1,075	750
13	Dried blood	100	76.5	23.5	100	85.0	15.0	1,175	750

Of the plats of the unlimed section, the maximum absorption of phosphate by the seedlings, 11.1 mgm, was from plat 9A receiving sodium nitrate, and the least absorption, 2.9 mgm, from plat 11A receiving ammonium sulfate. Plats receiving dried blood, calcium cyanamid, calcium nitrate, and one-half the regular amount of sodium nitrate, supplying 10.4 mgm, 8.9 mgm, 7.3 mgm, and 6.6 mgm, of phosphate, respectively, contained more phosphate available to the seedlings than the check plat which gave 5.3 mgm. Liming increased the phosphate absorption of all plats except 13B, which received dried blood. Plat 11B gave the maximum uptake of 22.1 mgm, followed by plats 8B and 9B with 16.6 mgm and 16.4 mgm, respectively. Plats 10B and 12B, receiving calcium nitrate and

calcium cyanamid, gave 13.3 mgm and 12.0 mgm, respectively, amounts considerably larger than plat 4, the check, with 10.8 mgm. The relative order of the various nitrogenous fertilizers as affecting

TABLE 6.—*Influence of source of nitrogen on phosphate availability as shown by the Neubauer method.*

Plat No.	Source of nitrogen	PO_4 content of seedlings in mgm Roots	Tops	Total	PO_4 removed from soil in mgm
		Unlimed Sections			
	Pure sand	7.3	25.0	32.3	—
4A	Minerals only	8.5	29.0	37.6	5.3
7A	No fertilizer	7.4	28.7	36.1	3.8
8A	½ $NaNO_3$	7.9	31.0	38.9	6.6
9A	$NaNO_3$	10.6	32.8	43.3	11.1
10A	$Ca(NO_3)_2$	9.8	29.8	39.6	7.3
11A	$(NH_4)_2SO_4$	7.2	28.0	35.2	2.9
12A	$CaCN_2$	9.5	31.7	41.2	8.9
13A	Dried blood	9.8	32.9	42.7	10.4
		Limed Sections			
4B	Minerals only	9.8	33.3	43.1	10.8
7B	No fertilizer	10.5	32.3	42.8	10.5
8B	½ $NaNO_3$	10.1	38.8	48.9	16.6
9B	$NaNO_3$	9.9	38.8	48.7	16.4
10B	$Ca(NO_3)_2$	11.4	34.2	45.6	13.3
11B	$(NH_4)_2SO_4$	11.3	43.1	54.4	22.1
12B	$CaCN_2$	9.6	34.7	44.3	12.0
13B	Dried blood	8.7	28.8	37.5	5.2

TABLE 7.—*Relative availability of inorganic phosphate in New Jersey soils as indicated by various methods using plat 9A as basis of comparison.*

Plat No.	Source of nitrogen	Displaced solution	Extracts Water	H_2CO_3	Leaching experiment	Neubauer method
			Unlimed Sections			
4A	Minerals only	61	37	17	25	48
7A	No fertilizer	43	8	19	5	34
8A	½ $NaNO_3$	69	78	60	68	60
9A	$NaNO_3$	100	100	100	100	100
10A	$Ca(NO_3)_2$	74	87	40	58	67
11A	$(NH_4)_2SO_4$	34	12	17	9	26
12A	$CaCN_2$	61	87	54	58	80
13A	Dried blood	108	24	46	58	94
			Limed Sections			
4B	Minerals only	174	303	266	88	97
7B	No fertilizer	435	256	281	112	95
8B	½ $NaNO_3$	261	240	216	119	150
9B	$NaNO_3$	270	316	335	164	148
10B	$Ca(NO_3)_2$	244	224	290	105	120
11B	$(NH_4)_2SO_4$	915	580	495	212	199
12B	$CaCN_2$	244	117	204	69	108
13B	Dried blood	470	34	33	12	45

phosphate solubility secured by this method agrees very closely with that secured by the preceding methods.

A comparison of the data on relative phosphate availability of the various plats as secured by the different methods is given in Table 7. Using plat 9A as the basis and giving to this plat the value of 100, plat 11A, receiving ammonium sulfate, has shown by the several methods used in the work relative phosphate availabilities of 34, 12, 17, 9, and 26. Plat 12A, receiving calcium cyanamid, gave values of 61, 87, 54, 58, and 80, while plat 10A gave essentially the same figures, *viz.*, 69, 78, 60, 68, and 60. Displaced solutions, water, and carbonic acid extracts of the plats of the limed section have indicated a greater increase in phosphate availability due to liming than is indicated by leaching and plant growth experiments. The difference in these two groups of methods indicates that a considerable portion of the increased amount of available phosphate is combined in compounds comparatively very soluble. This fact was noted previously in connection with the leaching experiment. All methods show, however, a marked increase in phosphate availability due to liming. This is especially true of plat 11B. They also show that the use of physiologically basic nitrogenous fertilizers has consistently increased and acid-forming nitrogenous fertilizers decreased phosphate availability when lime was not used to correct the acidic effects.

DISCUSSION

The use of physiologically basic nitrogenous fertilizers on the soils studied has resulted in increased availability and utilization of phosphate and decreased acidity, while the use of acid-forming nitrogenous fertilizers has had exactly the opposite effect when compared with the check plats and when lime has not been added to correct the residual acidic effects. Furthermore, as shown by work not reported in this paper, basic nitrogenous fertilizers increased the base saturation of the exchange complex, while acid-forming fertilizers greatly decreased it

These results may be explained principally by a consideration of the effect of the different fertilizers on the exchange complex of the soil. According to the generally accepted theory of the action of acid-forming fertilizers on the soil, the use of these salts causes an exchange of hydrogen for some base of the exchange complex of the soil, principally calcium. According to the theory advanced by Page (9), on the addition of ammonium sulfate to a soil, ammonium immediately replaces calcium, the latter forming insoluble calcium sulfate and thus being removed from the field of reaction. Am-

monium is subsequently nitrified to nitric acid by bacterial activity. The nitric acid thus formed reacts with more calcium of the soil, exchanging for the calcium two atoms of hydrogen. The addition of a physiologically basic nitrogenous fertilizer, on the other hand, introduces a base which replaces some of the hydrogen already in the exchange complex. Thus, acid-forming nitrogenous fertilizers reduce the base saturation of a soil, while physiologically basic nitrogenous fertilizers increase it.

The availability of phosphate in a soil is determined in part by the base with which it is combined. The continued use of acid-forming nitrogenous fertilizers reduces the amount of exchangeable calcium, magnesium, sodium, and potassium in the soil and increases the acidity of the soil so that more of the phosphate combines with iron and aluminum. Although the normal phosphates of iron and aluminum, as such, are relatively available to plants, they are very easily hydrolyzed, forming relatively unavailable basic phosphates of iron and aluminum. When lime is applied to such soils, however, the acidity is greatly decreased, and the calcium of the lime replaces much of the hydrogen of the exchange complex and furnishes calcium for the formation of the relatively available calcium phosphate. The use of physiologically basic fertilizers, instead of reducing the amount of base already in the soil actually increases it. Thus, sodium nitrate and calcium nitrate leave a residue of sodium and calcium after the nitrate has been used in plant growth. The phosphates of the soil combine with these bases instead of iron and aluminum, giving phosphates more readily available for plant growth. Since normal sodium phosphate is much more soluble than tricalcium phosphate, it would be expected that the plat receiving a sodium salt would contain more water soluble phosphate than a plat which receives a calcium salt. This situation obtains on the New Jersey soil, where there is more soluble phosphate on those plats receiving sodium nitrate than on those receiving calcium nitrate or calcium cyanamid. The difference on the Alabama plats apparently in favor of calcium cyanamid is explained by the fact that this fertilizer contains a large amount of free lime. The difference is thus due to the fact that more base is supplied in the calcium cyanamid than in sodium nitrate.

The following results of these various factors have been apparent throughout this work:

1. Acid-forming nitrogenous fertilizers decrease phosphate availability when lime is not added but do not decrease it significantly when lime is supplied.

2. Physiologically basic nitrogenous fertilizers increase phosphate availability whether lime is added or not.

3. Fertilizers leaving a sodium residue increase the solubility of soil phosphates more than fertilizers leaving a calcium residue.

SUMMARY

The influence of different sources of nitrogen on the availability of phosphate in soils from plats of the sources of nitrogen experiments of the Alabama, Rhode Island, and New Jersey Experiment Stations has been studied by the following methods:

(a) Concentration of inorganic and total phosphates in the displaced solution.

(b) Concentration of inorganic and total phosphates in 1:5 water extracts.

(c) Concentration of inorganic phosphate in 1:5 carbonic acid extracts.

In addition, the soils from the New Jersey Experiment Station were studied by other methods, as follows:

(a) Amount of inorganic phosphate removed from the soils by continued leaching.

(b) Amount of phosphate absorbed by the soils from a solution of mono-potassium phosphate.

(c) Amount of phosphate removed from the soil by wheat seedlings, using the Neubauer method.

All methods have shown that physiologically basic nitrogen fertilizers increase and acid-forming fertilizers decrease phosphate availability, as compared with the check plats, when lime is not applied.

Liming greatly increased the availability of the phosphate on all plats, and corrected the detrimental effects of the acid-forming nitrogenous fertilizers.

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TIME OF SEEDING AND TURNING VETCH FOR COTTON AND CORN[1]

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The use of vetch as a green manuring crop is becoming rather common in some sections of Alabama. The legume is fall planted, usually in cotton or corn middles, and plowed under the following spring before planting cotton or corn. In order to secure the best results with the crop, it is essential to know when the vetch should be planted in the fall and when it should be plowed under in the spring. This paper gives the results of three experiments on the time of planting and turning vetch for cotton and corn. All experiments were on Norfolk sandy loam at Auburn.

EXPERIMENT I

In experiment 1, monantha vetch, hairy vetch, and Austrian winter peas were planted on four different dates. On each planting date five plats were planted so that cuttings might be made at five different times in the spring. All plats were 1/500 acre and were in duplicate. The legumes were inoculated by the soil method and fertilized in the drill with basic slag at the rate of 600 pounds per acre. The seeding was at the rate of 20 pounds per acre for monantha and hairy vetch and 45 pounds per acre for Austrian peas.

In the spring the plats were cut by hand. The green weight, dry weight, and nitrogen content were determined. Tables 1 and 2 give the data obtained. These data show that the September 30th seeding produced the largest crop regardless of the cutting date. As the date of planting was delayed the crop produced was smaller. The data also show that in most cases the later cuttings gave the largest yields. Where this was not true the decreases were small and were due to shedding of leaves or insect injury. The increase in yield resulting from delayed cutting was not sufficient to compensate for the decrease in growth as a result of late planting. It is evident that by early planting a very good growth may be secured by the middle of March so that the crop may be turned under for either cotton or corn. The early planted legumes contained from 34.8 to 65.2 pounds of nitrogen per acre in their tops on March 10. As subsequent results will show, that amount of nitrogen in vetch will

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produce good crops of cotton and corn without the use of additional nitrogenous fertilizer.

EXPERIMENT II

This experiment included a study of the time of turning vetch and a comparison between vetch and nitrate of soda for corn. All vetch plats were planted at the same time The vetch on plat 4 was turned about March 15; that on plat 8, about April 1; and that on plat 12 was turned about April 15. The two-year average nitrogen content of the vetch on these plats was 32.6, 57.2, and 106.7 pounds

TABLE 1.—*Pounds of dry matter per acre of vetches and Austrian peas as influenced by time of seeding and cutting.*

Planting date	Date of cutting				
	March 10	March 22	March 31	April 15	May 2
	Monantha Vetch				
September 30	1,617	2,202	2,547	3,711	4,163
October 25	1,162	1,576	1,855	2,359	2,927
November 24	277	657	983	1,794	1,840
December 18	47	112	136	396	601
	Hairy Vetch				
September 30	1,281	962	1,231	1,270	967
October 25	615	659	930	1,259	961
November 24	74	248	404	892	614
December 18	25	66	113	254	216
	Austrian Peas				
Spetember 30	1,034	1,479	2,161	2,915	2,582
October 25	665	1,178	1,972	2,865	2,177
November 24	223	406	638	1,420	1,510
December 18	67	104	168	421	424

TABLE 2.—*Pounds of nitrogen per acre in vetches and peas as influenced by time of seeding and cutting.*

Planting date	Date of cutting				
	March 10	March 22	March 31	April 15	May 2
	Monantha Vetch				
September 30	65.2	73.8	89.4	112.9	110.3
October 25	41.6	53.7	58.4	72.2	71.7
November 24	11.5	24.0	39.5	62.8	51.0
December 18	1.8	4.2	5.5	14.0	15.6
	Hairy Vetch				
September 30	49.3	36.0	50.7	47.4	30.5
October 25	23.2	26.9	37.3	54.2	30.5
November 24	2.9	10.6	16.9	35.0	20.2
December 18	0.9	2.8	4.8	9.9	6.7
	Austrian Peas				
September 30	34.8	50.7	67.8	78.4	58.6
October 25	23.6	40.3	60.5	80.5	37.4
November 24	8.0	15.0	21.6	37.6	29.6
December 18	2.1	3.7	5.7	13.0	10.5

per acre, respectively. In addition to the nitrogen fertilization, all plats received annually 400 pounds of superphosphate (acid phosphate) and 50 pounds of muriate of potash per acre.

Table 3 gives the corn yields for 1926 and the average yield for 1925 and 1926. The yields in 1925 were very low due to a severe drought.

TABLE 3.—*Yield of corn following vetch or fertilized with nitrate of soda.*

Plat No.	Nitrogen treatment per acre	Time of planting	Yield of grain in bushels per acre 1925	1926	Average
1	None	April 5–8	4.6	2.3	3.45
2	100 pounds $NaNO_3$	April 5–8	10.0	17.5	13.73
3	200 pounds $NaNO_3$	April 5–8	8.8	28.1	18.47
4	Vetch, early	April 5–8	8.4	26.1	17.23
5	None	April 5–8	3.5	4.7	4.09
6	200 pounds $NaNO_3$	April 15–20	7.6	31.9	19.75
7	300 pounds $NaNO_3$	April 15–20	8.0	38.6	23.29
8	Vetch, medium	April 15–20[a]	8.9	37.3	23.10
9	None	April 5–8	3.2	5.2	4.21
10	200 pounds $NaNO_3$	April 28–30	10.4	30.8	20.62
11	400 pounds $NaNO_3$	April 28–30	7.5	33.6	21.55
12	Vetch, late	April 28–30	4.6	41.1	22.83
13	None	April 5–8	4.3	7.2	5.74

[a]First planting stand injured badly by worms. Planted over May 6.

The results show that the early turned vetch on plat 4 produced as good a yield of corn as did fertilization with 200 pounds of nitrate of soda. A comparison of plats 4 and 8 shows that a delay in time of turning vetch caused an increase in the yield of corn. Further delay in turning, however, did not cause an additional increase in yield, although the nitrogen content of the vetch was practically doubled. This is shown by a comparison of plats 8 and 12. Apparently, good vetch may be turned sufficiently early to prevent a delay in corn planting and at the same time sufficient nitrogen be plowed under to insure a good yield of corn.

EXPERIMENT III

This experiment was very similar to the preceding one, except cotton followed the vetch instead of corn. The rate of mineral fertilization was 600 pounds of superphosphate (acid phosphate) and 75 pounds of muriate of potash per acre per year. The time of turning the vetch and the nitrogen content of the vetch was essentially the same as that recorded in the experiment with corn. The results of the experiment are given in Table 4.

The results obtained with cotton differ from those obtained with corn in one important respect. Delay in turning the vetch with a consequent delay in time of planting reduced the yield of cotton.

TABLE 4.—*Yield of cotton following vetch or fertilized with nitrate of soda.*

Plat No.	Nitrogen treatment per acre	Time of planting	Yields of lint cotton in pounds per acre 1925	1926	Average
1	None	April 5–8	146.3	143.6	145.0
2	300 pounds $NaNO_3$	April 5–8	251.7	480.7	366.2
3	Vetch, early	April 5–8	252.3	405.5	328.9
4	Vetch, medium	April 20–22	188.1	426.6	307.4
5	None	April 5–8	133.3	125.0	129.2
6	Vetch, late	April 29–30	94.8	376.8	235.8
7	300 pounds $NaNO_3$	April 29–30	145.6	424.1	284.9
8	None	April 5–8	152.7	150.4	151.6

It is not a safe practice, especially under boll weevil conditions, to delay cotton planting. This is shown by a comparison of plats 2 and 7. Both plats were fertilized alike, but plat 7 was planted three weeks later than plat 2, causing an average decrease in yield of 81.3 pounds of lint cotton. The early turned vetch has more than doubled the yield of cotton and has produced almost as large a crop as 300 pounds of nitrate of soda.

SUMMARY

Experiments with monantha vetch, hairy vetch and Austrian peas as green manuring crops have shown that they should be planted early in the fall. Best results were secured when planted the latter part of September. Later plantings gave considerably smaller yields in the spring.

Vetch turned as early as March 15 produced large increases in the yield of cotton or corn. The increase was approximately equivalent to that obtained from the use of 200 to 300 pounds of nitrate of soda. When turned April 1 or April 15 an additional increase was obtained with corn. On the other hand, delayed turning reduced the yield of cotton, although the amount of nitrogen turned under was more than double the nitrogen content of the early turned vetch.

EFFECT OF SPACING ON YIELD AND SIZE OF COTTON BOLLS[1]

H. B. Tisdale[2]

The spacing of cotton is an important problem in economical production. The present method of thinning and cultivating cotton by hand labor is very expensive. If cotton could be planted so that it could be cultivated by machinery, the cost of production would be greatly reduced and the margin of profit increased. To know the number of cotton plants required per acre to produce the maximum yield would be of considerable advantage also in comparing yields from experimental plats, since perfect stands are seldom obtained.

A cotton spacing experiment has been conducted at the Alabama Experiment Station on fertilized and unfertilized soil for three years to determine the effect of spacing on the yield and size of bolls.

METHODS

All plats of the experiment were run in duplicate. The rows on all plats were 3½ feet apart. The seed was planted by hand under a wire line measured and marked for each spacing in the drill. The plants were thinned by hand at the usual time to the required number per hill. One, two, three, and four plants per hill were left at spacings of 6, 12, 18, 24, 30, and 36 inches in the drill. One-half of each plat was left unfertilized and the other half received 600 pounds of superphosphate (acid phosphate), 50 pounds of muriate of potash, and 300 pounds of nitrate of soda per acre. No attempt was made to control the boll weevil during the course of the experiment.

RESULTS

YIELDS OF SEED COTTON

The distribution and amount of rainfall during the three seasons 1924 to 1926 were widely different. Throughout the season of 1925 the rainfall was far below normal and very small increases in yield were obtained from the heavy application of fertilizer. The growth of the plants on all plats in 1925 was very small, reaching about half the size obtained in 1924 and 1926. The amount of rainfall during the growing seasons of 1924 and 1926 was about the same, but the distribution was considerably different. The first half of the growing season of 1924 had much more rainfall than the same period in 1926, and vice versa for the last half of the growing season. The wet

[1]Paper presented at the meeting of the Southern Section of the Society held in Auburn, Alabama, Aug. 24-25, 1927. Contribution from the Department of Agronomy, Alabama Agricultural Experiment Station, Auburn, Ala. Received for publication Dec. 17, 1927.

[2]Associate in Plant Breeding.

period of 1924 caused excessive shedding of squares on the thickest spaced cotton, and most of the fruit was set after the first half of the season. During the first half of the growing season of 1926 the cotton flea hopper destroyed most of the fruit causing a condition of plant growth very similar to that in 1924.

Table 1 shows the yield of seed cotton per acre and average for three years from each spacing.

TABLE 1.—*Pounds of seed cotton per acre in spacing experiments at Auburn, Alabama.*

Spacing			Fertilized				Unfertilized			
Inches in drill	Plants per hill	Plants per acre	1924	1925	1926	3-year average	1924	1925	1926	3-year average
6	1	24,890	1,170	726	1,254	1,050	717	695	348	587
6	2	49,780	893	726	1,140	920	717	612	260	530
6	3	74,670	730	708	1,025	821	568	590	189	449
6	4	99,560	788	664	920	791	475	612	268	452
12	1	12,445	1,175	722	1,021	973	735	682	352	590
12	2	24,890	1,201	831	986	1,006	656	761	374	597
12	3	37,335	1,100	752	1,078	977	700	686	330	572
12	4	49,780	990	739	1,104	944	656	686	365	569
18	1	8,296	1,267	814	876	986	682	823	290	598
18	2	16,592	1,412	818	1,096	1,109	748	779	356	628
18	3	24,890	1,276	761	1,170	1,069	625	730	396	584
18	4	33,184	1,219	748	1,197	1,055	647	748	365	587
24	1	6,223	1,236	849	836	974	664	796	304	588
24	2	12,445	1,298	893	1,140	1,110	796	858	365	673
24	3	18,668	1,219	876	1,126	1,074	814	779	378	657
24	4	24,890	1,188	770	1,148	1,035	669	695	414	593
30	1	4,978	999	840	704	848	625	722	260	536
30	2	9,956	1,263	889	845	999	603	796	308	569
30	3	14,934	1,324	880	884	1,029	726	796	286	603
30	4	19,912	1,289	876	937	1,034	700	730	308	579
36	1	4,148	1,012	792	660	821	541	691	268	500
36	2	8,296	1,280	840	748	956	730	726	317	591
36	3	12,445	1,316	880	739	978	686	713	348	582
36	4	16,592	1,289	871	766	975	502	717	400	540

The average results show that on both the fertilized and unfertilized land the largest yields were made from spacings of 24 and 18 inches in the drill with two plants per hill, or 12,445 and 16,592 plants per acre, respectively. It will be noted that there are only small differences in the yields from spacings giving 8,296 plants per acre and spacings giving 37,335 plants per acre.

The yields for each year show a relation to the seasonal conditions. The largest yields were obtained in 1924 and the lowest yields in 1925. It will be seen that in the extremely dry season of 1925 the

differences in yields from the thick and thin spacings are much smaller than they are in the more favorable seasons of 1924 and 1926. The highest yields for each of the three years were obtained from different spacings, but these spacings contained from 12,445 to 24,890 plants per acre.

SIZE OF BOLLS

One hundred sound mature bolls taken at random from each plat were weighed and the number of bolls per pound of seed cotton determined. Table 2 shows the number of bolls per pound of seed cotton and average for three years from each spacing.

These results show that the size of bolls decreased as the plants were crowded. It required 100 bolls on the unfertilized soil and 96 bolls on the fertilized soil to make of 1 pound seed cotton from the thickest spaced plats. The least number of bolls required to make

TABLE 2.—*Number of bolls per pound of seed cotton from each spacing.*

Spacing			Fertilized				Unfertilized			
Inches in drill	Plants per hill	Plants per acre	1924	1925	1926	3-year average	1924	1925	1926	3-year average
6	1	24,890	73	101	75	83	80	99	81	87
6	2	49,780	81	102	80	88	87	105	91	94
6	3	74,670	82	109	84	92	94	111	90	98
6	4	99,560	87	108	92	96	95	110	95	100
12	1	12,445	65	97	72	78	79	91	76	82
12	2	24,890	73	97	72	81	83	95	86	88
12	3	37,335	76	103	77	85	86	103	82	90
12	4	49,780	80	107	80	89	83	108	86	92
18	1	8,296	70	93	69	77	76	87	74	79
18	2	16,592	66	96	72	78	79	91	76	82
18	3	24,890	75	103	74	84	86	98	83	89
18	4	33,184	75	105	78	86	82	98	86	89
24	1	6,223	65	81	68	71	71	87	77	78
24	2	12,445	71	94	70	78	76	92	79	82
24	3	18,668	70	97	71	79	78	101	77	85
24	4	24,890	74	98	75	82	81	99	77	86
30	1	4,987	70	87	71	76	78	92	76	82
30	2	9,956	70	93	72	78	78	86	76	80
30	3	14,934	71	91	74	79	75	90	77	81
30	4	19,912	73	98	70	80	76	99	80	85
36	1	4,148	67	88	66	74	73	96	76	82
36	2	8,296	68	93	76	79	73	95	76	81
36	3	12,445	69	95	71	78	76	95	79	83
36	4	16,592	71	90	75	79	80	96	77	84

1 pound of seed cotton was from the plats spaced 24 inches in the drill with one plant per hill. With this spacing, 71 bolls on the fertilized soil and 78 bolls on the unfertilized soil were required to

make 1 pound of seed cotton. The bolls were smaller on the unfertilized than on the fertilized soil at each spacing. They were also smaller at each spacing in 1925, which was an extremely dry season, than in the other two years.

SUMMARY

A cotton spacing experiment was conducted for three years on fertilized and unfertilized land. The largest average yields were made from spacings of 24 and 18 inches in the drill with two plants per hill, or 12,445 and 16,592 plants per acre, respectively. There were only small differences in the yields from spacings giving 8,296 plants per acre and spacings giving 37,335 plants per acre. The differences in yields from all spacings were smaller in the extremely dry year 1925 than in the other two more favorable years of 1924 and 1926.

Thick spacing, low fertility, and dry weather were conditions that caused a decrease in the size of the boll.

REPORT OF THE COMMITTEE ON FERTILIZER DISTRIBUTING MACHINERY OF THE AMERICAN SOCIETY OF AGRONOMY[1]

The committee finds that the best method of fertililizer application or placement is affected by many factors and feels that on the basis of the present data only a few definite conclusions may safely be made. They are as follows:

I. Barring serious injury to germination, the nearer fertilizer is placed to the seed the more effective is the fertilizer in promoting early growth.

II. Of the individual carriers, those carrying nitrogen are most apt to cause injury to germination; those carrying potash stand intermediate; and those carrying phosphates are least apt to cause injury.

III. For practically all intertilled crops the safest method of hill and drill row application is to apply the fertilizer in bands along both sides of the seed and at a depth varying with the crop.

IV. A placement of fertilizer which is safe under all conditions of weather and soil will not give maximum results in many cases.

V. Before more definite and comprehensive recommendations can be made it will be necessary to do much more experimental work.

VI. The committee recommends that this experimental work be carried out according to the following outline.

FACTORS WHICH DETERMINE THE BEST METHOD OF APPLYING FERTILIZERS AND WHICH SHOULD BE CONSIDERED IN A COMPREHENSIVE PLAN FOR FUTURE INVESTIGATION

1. Climatic Sections Based on Temperature and Rainfall. Each climatic section is a unit in itself and the best method in one section may be a poor method in another section.

   (a) *Northern states section.*—A region characterized by moderate temperatures and generally favorable moisture conditions.

   (b) *Southern states section.*—A region characterized by a long growing season and a variable rainfall.

   (c) *Central interior section.*—A region characterized by frequent summer droughts and hot winds.

   (d) *Western states sections.*—Not as yet defined.

[1]Presented at the meeting of the Society held at Chicago, Ill., Nov. 17, 1927, by Dr. Emil Truog, for the committee, comprising Dr. Truog, Wisconsin, *Chairman*; Dr. J. R. Fain, Georgia; and Dr. F. E. Bear, Ohio. Reprints of this report may be had upon application to the Chairman of the Committee.

2. Kind of Crop.
   Each of the following presents a separate problem.
   - (a) Small grains
   - (b) Corn
   - (c) Cotton
   - (d) Sugar cane
   - (e) Hay crops
   - (f) Permanent pastures
   - (g) Lawns and golf turfs
   - (h) Potatoes
   - (i) Tobacco
   - (j) Sugar beets
   - (k) Peas and beans
   - (l) Garden crops
   - (m) Small fruits
   - (n) Orchard fruits
3. Purpose for Which Fertilizer is Used or Service that Fertilizer is Expected to Perform.
   It may determine entirely the method of application.
   - (a) Promote early growth
   - (b) Promote late growth
   - (c) Hasten maturity or growth
   - (d) Delay maturity
   - (e) Increase yields
   - (f) Improve quality
   - (g) Promote hardiness
4. Kind of Soil
   Each class of soil presents a different problem.
   - (a) Sands
   - (b) Sandy loams
   - (c) Silt loams, clay loams, and clays
   - (d) Peats and mucks
5. Kind of Fertilizer.
   Each fertilizer material and each mixture of two or more materials presents a separate problem, and there should be studied in each climatic section those materials and mixtures that are used or likely to be used in that section.
6. Amount of Fertilizer to be Applied.
   The amounts common for the section should be tried and these may be designated as follows:
   - (a) Low amount
   - (b) Medium amount
   - (c) High amount
7. Experiments under Controlled Greenhouse Conditions. It is suggested that the U. S. Department of Agriculture is best situated to do this and that funds for this work should be made available to some one in the Department who is qualified to direct the work.

VII. The committee further recommends that the Joint Committee of the American Society of Agronomy, the National Fertilizer Association, the National Association of Farm Equipment Manufacturers, and the American Society of Agricultural Engineers devise ways and means of carrying on comprehensive experiments along the lines just outlined.

VIII. It is also recommended that the President of the Society again appoint a committee to continue the work for the ensuing year.

NOTES

RELATIVE RESISTANCE OF OAT VARIETIES TO SHATTERING AT MORO, OREGON

Ninety-five varieties and strains of oats were grown in nursery rows at the Sherman County Branch Station at Moro, Oregon, in 1923 to determine their relative resistance to shattering and lodging under the semi-arid conditions of eastern Oregon. Estimates of shattering and lodging were made August 15, three and four weeks after the midseason and early varieties, respectively, were ripe. The data are summarized in Table 1.

TABLE 1.—*Relative resistance of 95 oat varieties to lodging and shattering at the Sherman County Branch Station, Moro, Oregon, in 1923.*

Varietal group	Number of varieties	Percentage of Lodging	Percentage of Shattering
Average Date of Ripening for Early Varieties, July 18			
Early white	9	64.2	12.5
Early yellow	14	40.7	10.4
Early red	8	24.4	17.9
Early gray	1	95.0	15.0
Early black	3	48.3	11.7
All early groups	35	45.2	12.9
Average Date of Ripening for Midseason (and Late) Varieties, July 25			
Midseason white	30	34.8	4.9
Midseason yellow	8	13.5	3.4
Midseason red	1	20.0	15.0
Midseason gray	2	52.5	7.5
Midseason black	11	26.9	7.0
Late side (all colors)	8	4.9	1.6
All midseason groups	60	26.8	4.9

Lodging in different varieties varied from 1 to 90% and shattering from 1 to 25%. Early varieties, as a group, lodged and shattered more than midseason varieties. However, some early varieties, especially Richland, showed a high resistance to both lodging and shattering. Some midseason varieties lodged very badly, but none shattered very much, possibly due to the fact that they did not stand as long after they were ripe as the early varieties. The varieties with red kernels, *viz.*, Kanota, Fulghum, and Burt, shattered more than any other group based on color.

The data, although for one year only, indicate that on the average lodging may be of more importance than shattering when the harvest of oats is delayed after they are ripe.—T. R. STANTON, D. E. STEPHENS, and B. B. BAYLES, *Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.*

MAKING A CORRECT MECHANICAL ANALYSIS OF SOILS IN FIFTEEN MINUTES

In previous communications[1] the use of the hydrometer method has been proposed as a rapid and simple method for the study of soils. A very comprehensive study has been made to ascertain if the method could be used for making a mechanical analysis of soils.

It has been discovered that if the soil particles are grouped into three main groups, such as sand, silt, and clay or colloids, that these three groups can be determined with remarkable accuracy by the hydrometer method in 15 minutes by making only two readings, one at the end of 1 minute and the other at the end of 15 minutes.

In making these studies about 30 different soils, whose complete mechanical analysis was known, were obtained from the United States Bureau of Soils. It was found that the percentage of material that settles out at the end of one minute in the regular hydrometer method is almost exactly the same as the percentage of all the combined sands obtained by the mechanical analysis method. If the percentage of material that settles out at the end of 15 minutes minus the sand which settles out at the end of 1 minute is considered to be silt, and if the material that still stays in suspension at the end of 15 minutes is considered to be clay or colloids, it was found that the mechanical analysis and hydrometer methods agreed quite closely in the soils whose silt content was composed mostly of the coarser size—in the neighborhood of 0.05—and disagreed rather widely in the soils whose silt content was composed of the finest size—in the neighborhood of 0.005.

This is as would be expected, because recent studies go to show that the finer silt has practically the same characteristics as the clay and should therefore be classed with the clay, while the coarser silt does not possess the same characteristics. The hydrometer method, therefore, includes in its clay or colloidal determination the finer

[1]BOUYOUCOS, G. J. Directions for determining the colloidal material of soils by the hydrometer method. Science, 66:16–17. 1927.

——————. The hydrometer as a new and rapid method for determining the colloidal content of soils. Soil Science, 23:319–331. 1927.

——————. The hydrometer as a new method for the mechanical analysis of soils. Soil Science, 23:343–353. 1927.

silt but not the coarser silt, consequently the hydrometer method would agree with the mechanical analysis method in soils with the coarse silt content but not with the finer silt content. In other words, the hydrometer and mechanical analysis methods agree almost perfectly in the determination of the combined sands, coarser silt, and clay. Where they disagree is in the finer silt. The mechanical analysis classes this fine silt with the coarse silt, while the hydrometer method classes this fine silt with the clay, because it has more of the characteristics of clay. Hence, there is no serious and radical disagreement between the two methods.

If it is desired to determine only the total sand and the total silt and clay, these determinations can be made by the hydrometer method in only one minute and will be astonishingly correct

Although the method may appear too ideal to be true, yet all the facts indicate that such is the case. Indeed, the method appears to be a rather remarkable and unique means of studying soils quickly, simply, and accurately. For practical purposes this method gives nearly all the information that is necessary and essential regarding the physical composition of soils, and in many cases this information seems to be more accurate than that obtained by the mechanical analysis method.

Finally, it should be stated that the recent criticisms of Joseph[2] and Keen[3] regarding the hydrometer method are not true and do not apply to the method as is shown elsewhere.—G. J. BOUYOUCOS, *Research Professor in Soils, Michigan State College, East Lansing, Mich.*

[2]JOSEPH, A. F. The determination of soil colloids. Soil Science, 24:271-274. 1927.

[3]KEEN, B. A. Soil mechanics and physics. Soil Science, 25:9-20. 1928

THE GENETICS OF SONORA WHEAT

In their Genetics Laboratory Manual, Babcock and Collins[1] mention in connection with wheat that the Sonora variety should not be used in hybrids as demonstrative material for beginners. This statement interested the authors of this note, and in order to learn what "characters behave differently from similar characters of other varieties" the variety Sonora was crossed with several other sorts. Clark, Martin, and Ball[2] describe this variety as being awnless, and this is one of the characters in which it is genetically different.

Several hundred crosses between awnless, or beardless, wheat varieties and awned, or bearded, varieties have been studied and in all cases the awnless varieties do not carry factors for the complete awned condition, excepting this one variety, Sonora. Since this is a rare occurrence, it seems worth reporting briefly here. The full account of the behavior in inheritance will be reported later.

When Sonora is crossed with other awnless varieties of common wheat (*Triticum vulgare*), such as Honor and Forward, the F_1 is awnless, while in the F_2 and later generations awned and partly awned types appear The results so far show a segregation that approaches a 15:1 ratio This indicates that Sonora, although awnless, carries a factor for the awned condition.

When Sonora is crossed with awned varieties there is a preponderance of awned plants. If Sonora did not carry a factor for awns, there would be a larger number of awnless than awned plants, as is the case when awnless and awned types are crossed. These studies are being carried further and the complete data will soon be assembled.---H.H. LOVE and W.J. CRAIG, *Department of Plant Breeding, Cornell University, Ithaca, N. Y.*

[1]BABCOCK, E. B., and COLLINS, J. L. Genetics Laboratory Maual. New York: McGraw Hill Book Co., Inc. 1918.

[2]CLARK, J. ALLEN, MARTIN, JOHN H., and BALL, CARLETON R. Classification of American wheat varieties. U. S. D. A. Bul. 1074. 1922.

ERRATA

CORRECTION BY B. A. BROWN

In Table 1 on page 110 of the February, 1928, issue of the JOURNAL, two corrections should be noted. Plat 9 received no fertilizer treatment and Plat 11 received 500 pounds of superphosphate (acid phosphate) in addition to the 100 pounds of potassium chloride noted in the table.

CORRECTION BY "STUDENT"

In my paper published in this JOURNAL (Vol. 18:703-719, 1926) there is a mistake in the table on page 719 where the reader is instructed to "Use Normal Curve with S. D. x $\sqrt{\frac{2}{16-3}}$ in the case of a Latin Square in which four varieties are to be tested with 16 replications."

While the tables printed in METRON (Vol. V, 3), make it unnecessary to use this approximation, it may be well to correct this mistake for the sake of those to whom METRON is not readily available.

If we are to use the tables of the normal curve in judging of the significance of the mean of a small sample, allowance must be made for the error in the determination of the S. D. This is done when evaluating the S. D. by dividing, not by the number of degrees of freedom, but by two less than this number (e. g. in a straight-forward case by n-3 instead of n-1). To convert this into the corresponding S. D. for use with the mean, it is further divided by n, the number in the sample.

In the table in question the number of degrees of freedom was 46, and for use with the normal curve the S. D. would be found by dividing by 44, but this would be multiplied by $\sqrt{\frac{2}{16}}$ to take into account the fact that the comparison is between two averages of 16 plats.

It should be remembered that, even with this correction, the normal curve tends to overestimate the significance of the means of small samples.

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THE NATURE OF BASE EXCHANGE AND SOIL ACIDITY[1]

H. W. Kerr[2]

Although much work has been done in the field of soil acidity, ideas concerning the exact nature of the acid soil constituents and the manner in which they function remain somewhat vague. In the present investigation, an attempt was made to gain some further information regarding the nature of the soil acids. It became apparent, very early in the work, that the phenomena of base exchange are intimately related to the subject. Hence, a study of the type of reaction involved in the exchange process was made as a preliminary to the work on the acids themselves.

It was Way (16, 17)[3] who first demonstrated the base exchange capacity of the soil 77 years ago. Since that time, many workers have contributed to our knowledge of the exchange process. Foremost among these are Van Bemmelen (15), Gans (3, 4), Gedroiz (5), Hissink (6), and Kelley and Brown (7), to mention but a few. No attempt will be made to review the extensive literature which has resulted from the researches of these and other workers. This has been very well done by Kelley and Brown (7) and by others.

It is evident that there is a lack of unanimity concerning the true nature of the mechanism involved in the exchange reaction. One school favors the theory that the phenomenon is one of adsorption, attributable to the highly dispersed condition of the soil colloids. On the other hand, it has been demonstrated that many of the char-

[1]Abstract of a thesis submitted at the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication Nov. 12, 1927.

[2]Government Fellow of Queensland, Australia. For the many suggestions and criticisms received in the course of this investigation the writer is grateful to Professor E. Truog under whose general supervision the work was done.

[3]Reference by number is to "Literature Cited," p. 334.

acteristics of the reaction point to true chemical forces as being the controlling factors in the process.

To elucidate this point, a series of equilibrium studies were planned. It was thought in this way to apply an appropriate mass action law to embrace the results obtained.

THEORY AND MATHEMATICAL EXPRESSION OF BASE EXCHANGE EQUILIBRIUM

CASE 1.—ACTIVE MASSES OF EXCHANGE COMPLEXES ASSUMED TO BE CONSTANT

The base exchange equilibrium appears at first thought to be similar to the well-known equilibrium between a solution of potassium carbonate and potassium sulfate in contact with barium carbonate and barium sulfate in the solid phase. This reaction may be represented thus, $BaCO_3 + K_2SO_4 \rightleftharpoons BaSO_4 + K_2CO_3$.

The presence of the solid phase of the barium salts serves to maintain a constant concentration of barium ions in the solution, and thereafter the solid phase is of no importance in the equilibrium state. The concentration of potassium ions is common to both anions, and by application of the Law of Mass Action of Guldberg and Waage the equilibrium equation should require $\frac{[CO_3'']}{[SO_4'']} = K$.

This case has been worked out by Meyerhoffer (9) who has shown that the above theory is in accordance with the facts.

A similar method of procedure may be applied to the soil exchange complex. For simplicity, the soil may be leached with a calcium chloride solution until its exchange complex is saturated entirely with calcium. The composition of the complex may be represented as CaX, where X is the unknown anion. The reaction between such a compound and a solution of magnesium chloride may then be written $CaX + MgCl_2 \rightleftharpoons MgX + CaCl_2$ in which the active masses of CaX and MgX are, similarly, assumed to be constant.

As before, the simplified mass action equation will be $\frac{[Mg^{++}]}{[Ca^{++}]} = K$.

An attempt was made to verify this theory in the following manner.

A sample of Miami silt loam was leached on a Büchner funnel with a normal calcium chloride solution and excess calcium chloride removed by washing. The soil was dried and passed through a 20-mesh sieve. Twenty-five-gram portions of this treated soil were transferred to shaking bottles and treated with 250 cc of solutions of magnesium chloride, the concentrations of which varied between 0.005 N and 0.045 N. The suspensions were shaken for 12 hours,

filtered, and 100-cc portions of the filtrate taken for the calcium and magnesium determinations. The values obtained are given in Table 1.

TABLE 1.—*Ca-Mg equilibria in exchange reaction, with Miami silt loam saturated with calcium.*

Equilibrium concentrations $CaCl_2$	$MgCl_2$	$K = \frac{MgCl_2}{CaCl_2}$
milli-equivs.	*milli-equivs.*	
6.4	21.0	3.3
7.6	35.6	4.7
8.0	46.6	5.8
8.4	57.0	6.8
9.0	73.4	8.2
9.4	95.4	10.2

In the calculation of K, the total concentrations of calcium and magnesium in the solution were taken as representing the relative proportions of the corresponding ions present. It was felt that this is justifiable as a close approximation when the solutions used are dilute and the salts concerned are so similar in nature as are the chlorides of calcium and magnesium. Moreover, since only the ratios of the concentrations are concerned, the calculations even at the higher concentrations should not be greatly in error.

It will be observed that the values for K vary continuously and do not approximate to a constant. The organic matter of the soil functions in the base exchange reaction, and it was thought that the variations in the K values might be attributable to the heterogeneous nature of the exchange complex in the soil used. In an attempt to eliminate this factor, a sample of Colby silt loam subsoil which was practically free from organic matter was tested in the same way as the previous soil. The results are shown in Table 2. The discrepancies in the values of K are even greater than before.

TABLE 2.—*Ca-Mg equilibria in exchange reaction, with Colby silt loam saturated with calcium.*

Equilibrium concentrations $CaCl_2$	$MgCl_2$	$K = \frac{MgCl_2}{CaCl_2}$
milli-equivs.	*milli-equivs.*	
3.4	2.2	0.65
5.2	5.7	1.10
6.4	10.0	1.56
7.3	14.3	1.96
7.9	19.0	2.41
8.2	23.2	2.83
8.4	28.7	3.42
8.7	33.4	3.84

Samples of peat and of zeolites were similarly tested, but the results were equally unsatisfactory. Obviously, the theory given does not apply in base exchange of soils.

CASE 2.—ACTIVE MASSES OF EXCHANGE COMPLEXES ASSUMED TO VARY

In formulating a possible mechanism for the exchange reaction there were several outstanding facts to be borne in mind. The great speed of the reaction led Gedroiz to disfavor a chemical reaction as describing the process. The writer found that the exchange reactions of the crystalline zeolites were particularly rapid. Equilibrium was attained very rapidly even when coarse material was used, and during the reaction the crystalline nature of the mineral apparently suffered no change. This was verified by a determination of the refractive indices of the crystals before and after treatment. The replacement of the calcium from stilbite by leaching it with 0.25 N hydrochloric acid resulted in but slight reduction of the indices, and this was due to the substitution of the heavier calcium ion in the space lattice by the lighter hydrogen ion.

These facts suggested a mechanism by which the cations in the solution may effect an exchange with those in the space lattice of the crystal, readily and rapidly. That the base may be completely substituted by cations from the extracting solution necessitates a comparatively open structure of the crystalline zeolites, which possess this property. Only under these conditions could free infiltration of the liquids and substances in solution take place. The specific gravities of the zeolites are characteristically low in value, when compared with those of the feldspars of similar composition. Thus, chabazite has a specific gravity of 2.1, while that of anorthite is 2.8. The ease of removal and readdition of the water of constitution of the zeolites support this view of an open structure.

With the idea in mind that the solid exchange complex has a perfectly open structure; that the exchange cations of the complex are freely accessible for rapid reaction as though in solution; and that as a consequence the active mass of any particular exchange complex varies directly with its total mass, an attempt was made to develop an expression which would describe the equilibrium conditions operating when a dissolved substance reacts with a solid of the nature described.

Consider the reactions as previously written, $CaX + MgCl_2 \rightleftarrows MgX + CaCl_2$. From a kinetic standpoint, the velocity of the forward reaction will depend on both the concentration of magnesium ions in the solution and the active mass of CaX in the solid phase.

The velocity may be written $V_1 = K_1 [Mg ++] [CaX]$.
Similarly, for the opposing reaction, $V_2 = K_2 [Ca ++] [MgX]$.
At equilibrium, $V_1 = V_2$

Or, $K_1 [Mg ++] [CaX] = K_2 [Ca ++] [MgX]$

And $\frac{K_2}{K_1} = K = \frac{[Mg ++] [CaX]}{[Ca ++] [MgX]}$.

To test the theory, this formula was applied to the experimental data given in Tables 1 and 2, and recalculations were made for K. As before, the values for the total equilibrium concentrations were treated as being proportional to the Ca ++ and Mg ++ present in the solution. The equilibrium values of CaX and MgX were readily calculable from a knowledge of the amount of calcium and magnesium in solution and the total replaceable calcium in the original calcium-saturated soil or zeolite. This last value was determined in the usual manner by leaching 25 grams of soil with 1,000 cc of normal ammonium chloride and determining the calcium in the extract.

TABLE 3.—*Ca-Mg equilibria in exchange reaction with Miami silt loam saturated with calcium.*

Trial No.	Total replaceable Ca in 100 grams soil	Equilibrium concentrations				
		$CaCl_2$	$MgCl_2$	CaX	MgX	K
	milli-equivs.	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	
1	12.2	6.4	21.0	5.8	6.4	2.99
2	——	7.6	35.6	4.6	7.6	2.83
3	——	8.0	46.6	4.2	8.0	3.14
4	——	8.4	57.0	3.8	8.4	3.06
5	——	9.0	73.4	3.2	9.0	2.90
6	——	9.4	95.4	2.8	9.4	3.04

TABLE 4.—*Ca-Mg equilibria in exchange reaction with Colby silt loam saturated with calcium.*

Trial No.	Total replaceable Ca in 100 grams soil	Equilibrium concentrations				
		$CaCl_2$	$MgCl_2$	CaX	MgX	K
	milli-equivs.	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	
1	11.3	3.4	2.2	7.9	3.4	1.89
2	——	5.2	5.7	6.1	5.2	1.29
3	——	6.4	10.0	4.9	6.4	1.20
4	——	7.3	14.3	4.0	7.3	1.08
5	——	7.9	19.0	3.4	7.9	1.04
6	——	8.2	23.2	3.1	8.2	1.07
7	——	8.4	28.7	2.9	8.4	1.19
8	——	8.7	33.4	2.6	8.7	1.17

It was a great satisfaction to find that the new values for K given in Tables 3 and 4 approximated fairly closely to a constant, and that the theory proposed may thus be the correct one. Considerable

discrepancies exist in the first numbers of Table 4 and other tables where the calculated values are greatly influenced by a small error in the analytical results. In addition, hydrolysis effects will be the greater, the lower the concentrations of salts in the extracting solutions. These effects may have been appreciable where the more dilute solutions were employed.

If the exchange complexes in the two soils were identical in composition, the values for K would be the same in both cases. These complexes probably vary from soil to soil, and there may exist in the soil an entire series of compounds, both organic and inorganic, each with its own equilibrium constant. The net effect of several constants is, however, a constant, and hence there is obtained with each soil a true constant K which represents the aggregate.

The results of Table 5 giving the equilibrium values for the magnesium-saturated soil may be compared with those of Table 3. They show that the value of K is independent of the side from which the equilibrium is approached.

TABLE 5.—*Ca-Mg equilibria in exchange reaction with Miami silt loam saturated with magnesium.*

Trial No.	Total replaceable Mg in 200 grams soil	Equilibrium concentrations CaCl$_2$	MgCl$_2$	CaX	MgX	K
	milli-equivs.	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	
1	21.2	0.5	5.1	5.1	16.1	3.25
2	——	1.7	7.9	7.9	13.3	2.85
3	——	3.4	10.3	10.3	10.9	2.92
4	——	5.5	12.1	12.1	9.1	2.91
5	——	7.8	13.5	13.5	7.7	3.03
6	——	11.1	15.1	15.1	6.1	3.36

In order to eliminate the factor contributed by the presence of the organic matter in the soil and thus to simplify the problem, a mild oxidation of the Miami silt loam was attempted by treating the soil with 3% hydrogen peroxide at a temperature of about 60° C. A

TABLE 6.—*Ca-Mg equilibria in exchange reaction with Miami silt loam oxidized and saturated with magnesium.*

Trial No.	Total replaceable Mg in 100 grams soil	Equilibrium concentrations CaCl$_2$	MgCl$_2$	CaX	MgX	K
	milli-equivs.	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	
1	9.0	2.1	3.3	3.3	5.7	0.90
2	——	3.5	5.1	5.1	3.9	1.89
3	——	6.4	5.8	5.8	3.2	1.64
4	——	8.9	6.5	6.5	2.5	1.89
5	——	11.5	6.8	6.8	2.2	1.82

microscopic examination of the residue after several days of treatment showed the soil particles to have clear, fresh surfaces. All of the organic matter was probably not destroyed by the treatment, yet it is felt that the most active portion as regards base absorption was eliminated. The residue was saturated with magnesium, and the resulting material employed in a series of equilibrium studies. The results are recorded in Table 6.

A comparison of these values with those obtained from the unoxidized soil and given in Table 3 shows that the oxidation resulted in the destruction of about 15% of the exchange capacity. Since this soil is rather poor in organic matter, the great activity of the latter in exchange phenomena is indicated and a further study of this follows.

IMPORTANCE OF ORGANIC MATTER IN THE EXCHANGE COMPLEX

Very little work has been done to determine the relative importance of organic matter in the soil exchange complex. To obtain further data on this point, a Carrington silt loam, a Colby silt loam, and a Waukesha silt loam were selected as types of somewhat different origin and containing varying amounts of organic matter. The total exchange capacities of these soils were determined before and after oxidation with hydrogen peroxide, and the results are given in Table 7. It is an interesting feature that the organic matter constituted a considerable proportion of the exchange complex.

TABLE 7.—*Base absorption power of three soils before and after oxidizing with hydrogen peroxide.*

Soil type	Absorption capacity per 100 grams soil		Difference	Absorption capacity due to organic matter
	Before	After		
	milli-equivs.	*milli-equivs.*	*milli-equivs.*	%
Carrington silt loam.	23.9	18.8	5.1	21
Colby silt loam. . . .	14.8	13.8	1.0	7
Waukesha silt loam.	25.1	18.2	6.9	28

In order to determine the equilibrium conditions of a soil whose absorbing complex is almost entirely organic in nature, a decomposed peat was used. The mineral matter present was low in amount and consisted largely of quartz sand. The calcium-saturated material was employed in a series of equilibrium trials. Table 8 gives the results. A considerable degree of hydrolysis occurred in these tests, but this does not vitiate the applicability of the equation provided the proportions of MgX at equilibrium be determined. In the calculations this value was taken as equivalent to the Mg which had been

taken from solution. The value for CaX was determined as before. The agreement in the values for K are as close as could be expected. It is interesting to note that the total exchange capacity of this material is equal to 3.16% of the weight of the peat. The importance of the organic material of the soil in this regard is thus further emphasized.

TABLE 8.—*Ca-Mg equilibria in exchange reaction with decomposed peat saturated with calcium.*

Trial No.	Total replaceable Ca in 100 grams soil	Equilibrium concentrations				
		$CaCl_2$	$MgCl_2$	CaX	MgX	K
	milli-equivs.	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	
1	158	12.2	2.5	146	5.5	5.4
2	—	14.8	4.1	143	7.9	4.9
3	—	17.8	6.1	140	9.9	4.8
4	—	20.2	7.6	138	12.4	4.2
5	—	22.6	9.8	135	14.2	4.3
6	—	24.6	12.2	133	15.8	4.2

APPLICATION OF THE PROPOSED THEORY TO ZEOLITE EXCHANGE REACTIONS

The foregoing results with soils have substantiated fairly well the theory proposed to describe the nature of the base exchange reaction. Since soils resemble the zeolites very closely in their mode of base exchange, it was thought desirable to conduct a series of experiments with the zeolites. Several well-known zeolites were available in small amounts. A trial of these showed chabazite and stilbite to possess the desired qualities, but the absence of adequate amounts necessitated the use of the commercial products employed as water softeners. Two general types of compounds are in use, *viz.*, the crystalline, usually a natural product; and the colloidal gel, a hydrated alumino-silicate formed by precipitation processes. A representative of both classes was used in the experiments. The natural product was the so-called permutite, which is prepared from green sand by suitable treatment. The mineral which constitutes the greater proportion of this material is glauconite, a compound of rather variable composition. Its formula may be written $(K,Na)(Fe,Mg)(Fe, Al)Si_6O_{18}\ 3H_2O$. The artificial product was obtained in the form of white opalescent grains. An analysis showed it to have a composition approximating that required by the formula $Na_2O \cdot Al_2O_3 \cdot 6SiO_2 \cdot 6H_2O$. In the form of its calcium salt, it is identical in composition with the crystalline zeolite, stilbite.

Samples of each of these substances were saturated with calcium and magnesium as described for the soils. Ten-gram samples were

treated with 250 cc of the appropriate chloride solution of suitable concentrations. Ample time with continuous shaking was allowed for the attainment of equilibrium. The results obtained and the calculated values for K are given in Tables 9 and 10.

TABLE 9.—*Ca-Mg equilibia in exchange reaction with permutite saturated with calcium.*

Trial No.	Total replaceable Ca in 40 grams material	Equilibrium concentrations $CaCl_2$	$MgCl_2$	CaX	MgX	K
	milli-equivs.	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	
1	10.2	3.9	5.6	6.3	3.9	2.34
2	——	4.7	9.0	5.5	4.7	2.24
3	——	5.2	13.1	5.0	5.2	2.43
4	——	5.5	16.7	4.7	5.5	2.62
5	——	5.8	20.8	4.4	5.8	2.73
6	——	6.1	24.8	4.1	6.1	2.75

TABLE 10.—*Ca-Mg equilibria in exchange reaction with artificial zeolite saturated with magnesium.*

Trial No.	Total replaceable Mg in 40 grams material	Equilibrium concentrations $CaCl_2$	$MgCl_2$	CaX	MgX	K
	milli-equivs.	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	*milli-equivs.*	
1	64.5	0.57	7.6	7.6	56.9	3.41
2	——	1.38	11.6	11.6	52.9	3.40
3	——	3.07	16.1	16.1	48.4	3.10

The values for K are quite satisfactory and suggest that the natural and artificial zeolites follow the same mechanism in their base exchange reaction as do soils. Gans (3, 4) in his work on the zeolites attempted to show the parallelism between the two by the use of other methods. In working over some of the data which he reports from an experiment with stilbite, an interesting confirmation of the previous results is obtained. He treated two portions of stilbite with an excess of concentrated ammonium chloride solution and determined the amounts of calcium replaced. The values were

(a) 2.5-gram sample yielded 0.035 gram Ca.

(b) 5.0-gram sample yielded 0.050 gram Ca.

The reaction may be represented as follows in which equilibrium concentrations of each in milli-equivalents are represented by the lower letters:

$$\underset{A}{CaX} + \underset{y}{2\,NH_4Cl} \rightleftharpoons \underset{x}{CaCl_2} + \underset{x}{(NH_4)_2X}$$

Then $K = \dfrac{Ay^2}{x^2}$.

Now A and y are large and suffer little reduction in value during the reaction; hence we may write, as an approximation, y = constant, and A = constant.

Then $K_1 = \frac{A}{x^2}$, and A is proportional to the weight of zeolite employed.

Suppose A = B in case (a)

Then A = 2B in case (b).

We have—

(a) $K_1 = \frac{B}{(0.035)^2} = \frac{B}{0.0123}$.

(b) $K_1 = \frac{2B}{(0.05)^2} = \frac{2B}{0.025} = \frac{B}{0.0125}$.

EQUILIBRIA BETWEEN CALCIUM AND HYDROGEN IN EXCHANGE REACTIONS

The introduction of ions of different valences in the exchange reactions offers no difficulties to the theory outlined, but the complication is introduced that the true ionic concentrations may not readily be determined in the mixture of ions. In soil acidity the most important ion of all is hydrion, and fortunately, its true concentration may be measured directly by several methods. The quinhydrone method was found suitable and convenient, and was employed in this work.

The expression previously developed for the calculation of the equilibrium constant must be modified here to embrace ions of different valances. Letting CaX represent the composition of the exchange complex, $CaX + 2\,HCl \rightleftharpoons CaCl_2 + H_2X$

Equilibrium concentrations

$$\begin{array}{cccc} A & y & x & x \end{array}$$

Then $K = \frac{x^2}{A\,y^2}$ or $= \frac{x}{B\,y}$ where $B = \sqrt{A}$

TABLE 11.—*Ca-H equilibria in exchange reaction with permutite saturated with calcium.*

Trial No.	Total replaceable Ca in 40 grams material *milli-equivs.*	Equilibrium concentrations $CaCl_2$ *milli-equivs.*	H^+ *milli-equivs.*	CaX *milli-equivs.*	H_2X *milli-equivs.*	K
1	10.2	0.54	0.015	9.7	0.54	11.5
2	——	1.6	0.040	8.6	1.6	13.5
3	——	2.4	0.066	7.8	2.4	13.0
4	——	3.0	0.080	7.2	3.0	14.0
5	——	3.7	0.115	6.5	3.7	12.6

To test the validity of this equation, a sample of permutite of which the exchange complex was saturated with calcium was used. Suitable solutions of hydrochloric acid were employed as extractants, and the hydrogen ion concentrations of the suspensions were determined. The filtered extracts were analyzed for replaced calcium. Table 11 shows the results obtained.

It will be seen that the values for K approximate fairly closely to a constant.

Now, the use of ions of mixed valence in the equilibria studies gives wider information than is afforded by employing calcium and magnesium, for the expression which gives a constant value for K must embrace the correct valence of the anion of the absorbing complex. An illustration will make this clear. The equation obtained above, assuming this radical to be divalent, was $K = \frac{x^2}{A\ y^2}$.

Suppose, now, that the anion be univalent. This gives the following expression in which the lower letters represent the equilibrium concentrations in milli-equivalents:

$$\underset{A}{CaX_2} + 2\ \underset{y}{HCl} \rightleftarrows \underset{x}{CaCl_2} + 2\ \underset{x}{HX}.$$

The equilibrium expression, then, is $K = \frac{x^3}{A\ y^2}$.

Hence, if the expression which gives the constant value for K is determined, the valence of the anion of the exchange complex follows. This method should be particularly useful in its application to the soil complex. But the attendant difficulties will be increased in this case. The soil may contain exchange materials of which the anions do not all possess the same valence. The degree of unsaturation and hence the proportion of the free alumino-silicic acid present will be uncertain, for as yet we have no accurate method of determining this quantity in the complex soil. For convenience it has been customary to determine the absorption capacity by leaching with salt solutions or treating the soil with alkaline hydroxide solution up to a pH 7, but this is certainly not the point at which the acid is completely neutralized with base, for the reaction of a mineral salt such as $Na_2O.Al_2O_3.6\ SiO_2$ is in the neighborhood of pH 10 to 11. The addition of alkaline hydroxide up to this point, however, will introduce serious errors from side reactions involving the oxides of aluminum and silicon; and if the acidity introduced by the use of hydrochloric acid with the soil falls below about pH 4, the solubility of aluminum oxide again becomes a factor, while calcium may be dissolved from compounds other than the exchange complex.

APPLICATION OF EQUILIBRIUM FORMULA IN AVAILABILITY STUDIES

With the limitations just mentioned in mind, an attempt was made to determine the equilibrium values for a sample of Superior clay saturated with calcium. These values are given in Table 12. Though the results obtained do not permit of application of the equilibrium formula, they do not lose any of their practical value in availability studies. In discussing this point, the vital factor introduced by the plant will not be considered, but the ease of solubility of the absorbed base as measured by the use of dilute acid will be taken as indicative of its availability. If a soil whose complex is saturated with calcium be treated with appropriate volumes of a dilute acid solution, calcium will be replaced by hydrogen. The process will proceed until definite equilibrium values are established. Assuming the simplest case, where the complex is uniform in composition and of the formula CaX, the equation is $CaX + 2\ HCl \rightleftarrows CaCl_2 + H_2X$.

This gives $K = \dfrac{(Ca^{++})\ (H_2X)}{(H^+)^2\ (CaX)}$.

TABLE 12.—*Ca-H equilibria in exchange reaction with Superior clay loam saturated with calcium.*

Trial No.	Replaceable Ca in 40 grams material *milli-equivs.*	pH of extract	Equilibrium concentrations CaCl₂ *milli-equivs.*	H+ *milli-equivs.*
1	16.5	6.13	2.21	0.08×10^{-2}
2	——	5.67	2.99	$0.21 \times$——
3	——	5.34	3.54	$0.46 \times$——
4	——	5.12	3.90	$0.76 \times$——
5	——	4.98	4.22	$1.10 \times$——

For the sample of permutite tested, the value of K was about 12. Hence in the initial stages of calcium extraction, where the value of CaX is high and H_2X low, there will result a relatively high solubility of calcium ions at a low hydrogen-ion concentration. That is, the calcium is very readily available. But as the removal of calcium from the complex proceeds, the value of H_2X increases, while that of CaX decreases, so that the dissolution of subsequent amounts of calcium is brought about only at increasing hydrogen-ion values, as required by the equation. In other words, the availability of the calcium in a pure compound of this kind is a variable factor, being governed by the degree of saturation of the compound with exchangeable base. Theoretically, the last trace of base is removed only at an infinitely high value of the hydrogen-ion concentration. Under natural soil conditions the calcium liberated is continuously abstracted either by crop feeding or by the process of leaching, which greatly aids the replacement of calcium by hydrogen.

The equilibrium expression which shows the relation between the degree of saturation of the exchange complex and the availability of its base is a quantitative statement of the conclusions drawn by Parker and Pate (11) from the results of their researches on base exchange. They found a general correlation between the degree of "unsaturation" of the soil absorbing complex and the difficulty of replacement of the residual bases by employing a solution of potassium acetate as the extractant.

Naturally, the correlation secured between different soil types by employing this method will be quite satisfactory only where all the exchange complexes are uniform in composition. Further, the salt employed in the extracting solution will be specific in its reaction in that the cation will govern the value of the equilibrium constant for the reactions.

EXAMINATION OF SOIL FOR ZEOLITE MINERALS

It is evident that a striking similarity exists between the behavior of the zeolites and the soil complex in exchange reactions; and in consideration of the fact that the soil may provide, at certain stages, conditions admirably suited for the formation of zeolitic compounds, it would seem inevitable to conclude that such compounds actually exist in the soil. It is well known that the exchange capacity of the soil is largely associated with the colloidal material present. But the results of several workers have shown that other of the soil fractions, notably the silts, may display appreciable reactivity. Thus, Gedroiz rather preferred to speak of the "zeolitic" portion of the soil in his discussion of the exchange complex than of the "colloidal" portion, although he subscribed to the adsorption view as describing the mechanism of the reaction. He thought of these larger particles as possessing "inner surfaces", and hence ostensibly colloidal in nature.

A very accurate and yet simple technic which allows of the definite characterization of fine mineral grains has recently been developed and perfected by Dr. R. C. Emmons.[4] The method is based on the measurement of the refractive indices of the mineral and a determination of its optical sign and crystallographic characteristics. The refinements he has introduced make it possible to determine accurately the refractive indices of particles as low as 0.003 mm in diameter. This method permits of the ready examination of the silt, whose particles range from 0.05 to 0.005 mm in diameter.

[4]Professor of Geology, University of Wisconsin, to whom the writer is greatly indebted for assistance and advice in connection with the mineralogical analysis.

It is possible that the exchange reaction displayed by the coarser fractions of the soil mass is due to the presence of a coating of active material either organic or inorganic in nature. In an examination of these fractions it would be desirable to remove the extraneous materials as far as possible.

The soil employed was a Colby silt loam subsoil, characteristically low in organic matter. By treatment with hydrogen peroxide, as already described, the organic compounds were largely removed. The residue was shaken for 48 hours with water containing a little ammonium hydroxide to ensure complete disintegration of the compound soil particles. The silt fraction of the residue was obtained by the usual method of mechanical analysis. Care was taken to insure the complete removal of all clay particles. The product was saturated with calcium by the method described. After this treatment, the silt was found to yield 6.1 milli-equivalents of replaceable calcium per 100 grams. A determination of the ammonia absorbed during the process of leaching with ammonium chloride showed that 6.3 milli-equivalents were held by 100 grams of the silt. This proved the exchange nature of the reaction.

The prepared material was subjected to mineralogical analysis by the microscopic method to determine the presence of zeolitic compounds capable of the observed reaction. A word of explanation should be given here to define the exact significance which is implied by the use of the term zeolite. The mineralogist applies this name to a group of secondary minerals which are alumino-silicates of the alkalies and alkaline earths. They resemble the feldspars in composition but possess, in addition, water of constitution. That some of these compounds exhibit base exchange properties is rather of secondary importance from the point of view of this classification. But the term zeolite is used by the soil scientist to designate a mineral compound which possesses, essentially, the capacity for the base exchange reaction. It is in the latter sense that the term is employed here.

The analysis showed one predominating compound of this nature, the mineral leverrierite. It has the formula $Al_2O_3 \cdot 3SiO_2 \cdot 3H_2O$, but presumably the molecules of water are not all combined in the same manner, for the mineral usually contains more or less Ca and Mg. The compound so formed with calcium might be of the composition $CaO \cdot Al_2O_3 \cdot 3SiO_2 \cdot 2H_2O$. The mineral occurred to the extent of about 2% in the sample of silt examined. Leverrierite is the active constituent of the clay-like material bentonite. This substance, after special processing, was one of the earlier materials employed as a commercial water-softener by virtue of its exchange capacity.

It must not be concluded that leverrierite is the mineral responsible for the base exchange properties displayed by all soils, although this mineral is of rather widespread occurrence. On the contrary, it is most probable that an examination of soils of other types and origins will reveal further interesting compounds of a like nature.

DISCUSSION OF NATURE AND ORIGIN OF BASE EXCHANGE IN SOILS

The foregoing results indicate a very close analogy between the exchange reaction shown by the zeolites and that displayed by soils. It is generally conceded that the zeolites are definite chemical compounds of characteristic crystalline form, and in the exchange reaction they conform with the stoichiometric laws of pure chemistry. A perfect analogy exists with the inorganic material of the soil, excepting that the reacting portion of the soil is chiefly in the colloidal condition. This point has been stressed by the adherents of the adsorption theory who attempt to show that the reaction involves adsorptive forces.

If the colloidal nature of the material plays an important part because of adsorptive properties, it would be expected that kaolin, an alumino-silicate which consists largely of colloidal material, would display pronounced exchange capacity. A sample of this material was leached with calcium chloride solution and a determination made of the exchangeable base absorbed. The kaolin showed a small though definite capacity in this respect, absorbing 1.8 milli-equivalents of replaceable calcium which is only about 0.5% of what a similar mass of zeolitic material would hold. Moreover, it seems that even this slight absorption was due to a small amount of an alumino-silicate present in the kaolin as an impurity and possessing the peculiar exchange capacity.

The inability of the kaolin to absorb bases is not surprising, for a very large series of alumino-silicate minerals is known, and but few of them show the capacity of ready and pronounced base exchange. Even the true zeolites differ markedly from member to member in the ease with which they react. It is only logical to conclude therefore, that the exchange power is intimately related to a definite arrangement of the atoms in the molecular structure.

As regards the "adsorption isotherm" form of the curve obtained by plotting the values for the "adsorbed" base against the concentration of the base in the extracting solution, the equilibrium values determined in the experiments with zeolites are perfectly amenable to this treatment, although no one questions the true chemical nature of the reactions involved. As an illustration the results of Table 9

are plotted in Fig. 1. The characteristic adsorption form of the curve, then, has little value from a diagnostic standpoint.

Nothing very definite can be stated with respect to the proportion of exchange complex present in the soil. If it be assumed that the complex will retain 7% of its weight of calcium, which is the pro-

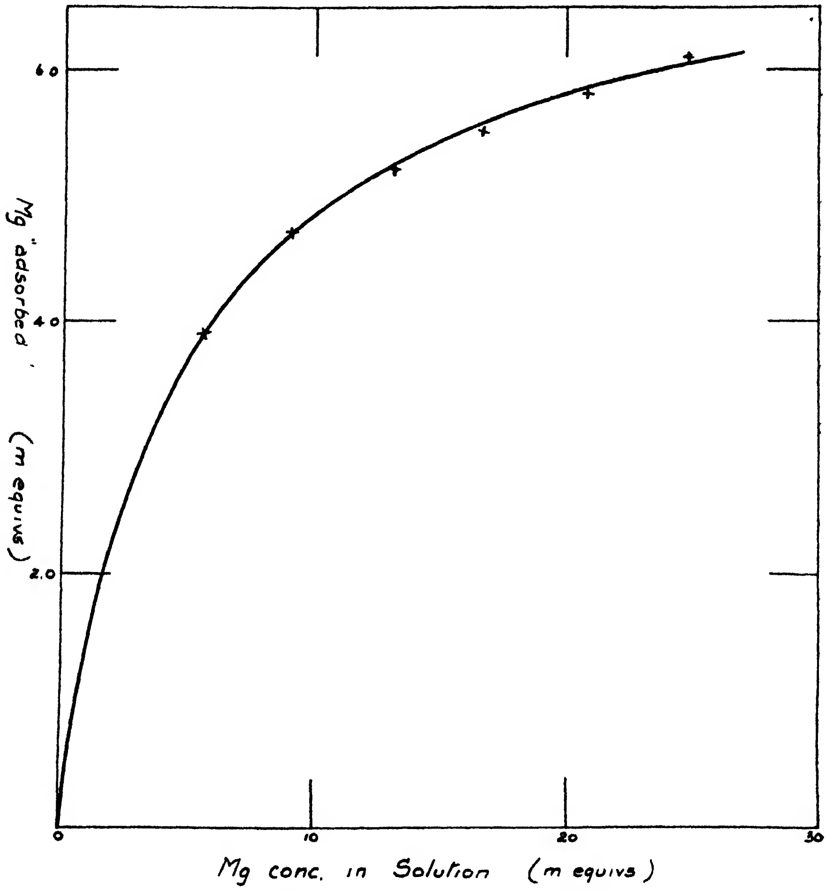

FIG. 1.—"Adsorption Isotherm" curve for exchange reaction with permutite.

portion in stilbite, then, for the soils examined in the course of these experiments, there would be present in the inorganic portion the following amounts of zeolitic material:

Carrington silt loam	5.4%
Colby silt loam	4.0%
Waukesha silt loam	5.2%

These values are considerably lower than the percentages of colloids present in these soils.

Bradfield (1) showed that the colloidal fraction of soils contains mainly SiO_2, Al_2O_3, and Fe_2O_3, and that its behavior is not identical with that of a physical mixture of these three oxides in the colloidal state. He concluded that the material consists mainly of alumino-silicates.

It is a well-established fact that the physical condition of the soil is governed primarily by the bases which are held in the exchange complex. If sodium predominates, the result is a dispersion of the finer material, or the soil is deflocculated. Calcium, on the other hand, gives a high degree of flocculation. It seems very suggestive that this small proportion of exchange complex in the colloidal state may exert considerable influence on the condition of the other colloidal material present. In the form of the sodium salt it may function as a protective colloid and stabilize the dispersion of the free oxides of iron, aluminum, and silicon. When calcium is added, the sodium is displaced from the complex and precipitation or flocculation of the entire colloidal mass results.

This behavior would be analogous to that displayed by the salts of oleic or stearic acids. The sodium salts of these acids are highly colloidal and possess considerable peptizing power for other inert colloidal material. If a soluble calcium salt be added to the dispersion, the immediate precipitation of the insoluble calcium soap is brought about and the flocculation of the entire dispersion results. Such a mechanism would account for the very variable composition of the soil colloids and would explain the presence of the iron oxide which is always found.

If it be concluded that the exchange complex of the soil is composed of the salts of one or more alumino-silicic acids, it will be necessary to offer a suggestion as to how these compounds might be formed in the soil. Burgess and McGeorge (2) have shown that in alkali soils solutions of sodium aluminate and sodium silicate interact to give an insoluble alumino-silicate. Now, even under humid conditions where alkali salts do not accumulate, there may be at times in the early stages of weathering sufficient concentrations of sodium carbonate to dissolve oxides of aluminum and silicon which then react and form alumino-silicates.

As the soil weathering process advances, the bases in the soil solution become chiefly calcium and magnesium, and that is why the bases of the absorbing complex are chiefly these two.

CAUSE AND NATURE OF SOIL ACIDITY

In 1916 Truog (13) strongly opposed the adsorption theory of soil acidity and furnished data in favor of the purely chemical theory.

The chemical theory has steadily gained supporters, and those still clinging to the adsorption theory are now greatly in the minority. It is now quite generally agreed that the alumino-silicic acids are the active inorganic compounds which function in acidity of mineral soils. Most attempts which have been made to determine the behavior of these substances have been confined to a study of the natural soil.

A forward step in the elucidation of the problem was that taken by Bradfield (1), who sought to isolate the true colloidal material from the soil mass. Unfortunately, other substances than just those active in soil acidity and base exchange are obtained by this method.

The activity of the salts of alumino-silicic acids in base exchange has been amply demonstrated. It might be expected, then, that the free alumino-silicic acids should be equally active themselves. If the alumino-silicates investigated by the writer are of the type existing in the soil, then it should be possible to produce from them the free alumino-silicic acids which would be identical in their reactions with those of the acid soil

The same zeolitic materials which were previously employed in the base exchange studies were made the starting point in the investigation of the nature of the alumino-silicic acids. The removal of the exchangeable base and its replacement by hydrogen necessarily involves the use of an acid. Gedroiz studied this aspect rather completely, and concluded that the most desirable solvent for the removal of the soil exchange bases is 0.05 N hydrochloric acid. The reaction may be carried out rapidly, and the decomposition of the soil exchange complex is slight This extractant was employed uniformly in all work where the replacement of the cations by hydrogen was involved.

PREPARATION AND PROPERTIES OF ALUMINO-SILICIC ACID

A sample of 100-mesh permutite was leached with 0.05 N hydrochloric acid and then thoroughly washed with distilled water, dried for 12 hours at 105°C and powdered. An electrometric determination on a 1 to 5 suspension of this material gave a pH of 3.22. It seemed rather strange that such an insoluble material could display such a high degree of acidity. It was thought that possibly some hydrochloric acid had been retained. Accordingly, rewashing was resorted to. As a further test, suspensions were prepared with varying ratios of solid to water, for the presence of a small amount of hydrochloric acid would reveal itself in dilution effects. The results are given in Table 13.

TABLE 13.—*pH values of permutite residue after leaching with hydrochloric acid and washing with water.*

Amount washed	Ratio permutite to water			
	1 to 2.5	1 to 5	1 to 25	1 to 50
	pH	pH	pH	pH
Washed		3.22		
Rewashed		3.34		4.21
Rewashed twice	3.25		3.92	

The effect of the excessive washing was to produce but slight effect on the hydrogen-ion concentrations of the suspensions as prepared. Yet the ratio of solid to water had marked influence on the results.

To confirm further the absence of chlorides, the residue was extracted with dilute calcium hydroxide solution. This method should enable any adsorbed acids to be removed completely. The extract, on acidification with nitric acid, produced not the faintest opalescence when silver nitrate solution was added. It was calculated that the proportion of hydrochloric acid necessary to produce the observed pH value would be sufficient to yield a decided precipitate of silver chloride.

A sample of Cecil clay loam, a highly acid soil from Alabama, was submitted to leaching with 0.05 N hydrochloric acid. The residue showed a pH value of 4.21. There existed the possibility in this case that the low pH value recorded was due to the organic acids of the soil. To eliminate this factor, the sample was oxidized with hydrogen peroxide before leaching. The pH value of the resulting suspension was 4.04 which is even lower than that of the unoxidized soil. The inorganic nature of the acids present was thus confirmed.

The colorimetric method was applied to a filtered extract of the acid-leached permutite. The method of ultrafiltration devised by Truog (14) was used. A perfectly clear extract was obtained and its pH value, colorimetrically, was 3.8. Moreover, the extract showed considerable titrable acidity, 400 cc of the clear filtrate requiring 5.3 cc 0.04 N calcium hydroxide solution for neutralization. This seemed to offer a ready method for the isolation of the acid itself, and a larger volume of the extract was sought for the purpose of evaporation and analysis of the residue. To aid in the filtration of this larger volume, an unglazed porcelain pressure filter was employed. Two liters of the perfectly clear filtrate were titrated, as before, but now two drops of the alkali gave a strongly pink color to phenolphthalein.

The results were confusing, and the only possible explanation was that the alumino-silicic acid which displayed this peculiar behavior was colloidal in nature. The fine particles could pass through the

pores of the first filter but were retained by the porcelain filter.

Further confirmation of this conclusion was obtained by attempting to obtain the acid by dialysis, employing a colloidion sack. After 48 hours, the pH value of the dialysate was identical with that of the conductivity water employed in the test. An experiment with the artificial zeolite gave the same result. The acid-leached substance in aqueous suspension gave practically the same reaction as that of the conductivity water employed. This material was quite coarse and settled readily. Another finely powdered sample gave quite a different effect. A suspension of this product at different ratios of solid to water gave electrometrically:

Ratio solid to water	pH of suspension	H-ion concentration
1 to 5	3.99	1.0×10^{-4} gram per liter
1 to 25	4.71	0.2×10^{-4} gram per liter

Only when the material is in the colloidal state does the suspension display a low pH value, and the H-ion concentration is then directly proportional to the amount of solid taken in the preparation of the suspension. This would be expected on the basis of a colloidal acid. A re-examination for this relationship of the values obtained when acid leached permutite was used yielded the following results:

Ratio permutite to water	pH of suspension	H-ion concentration in grams per liter
1 to 25	3.42	0.38×10^{-3}
2 to 25	3.10	$0.80 \times$ ——
3 to 25	2.96	$1.10 \times$ ——
5 to 25	2.71	$2.0 \times$ ——
10 to 25	2.14	$7.3 \times$ ——

With the exception of the value given by the heaviest suspension, the H-ion concentrations are proportional to the mass of permutite taken.

Further interesting properties were shown by these suspensions as follows: The potentiometric readings varied considerably with the position of the electrode when the values were recorded. With the electrode first in the supernatant liquid, and second, immersed in the sediment of a 1 to 2.5 suspension, pH values of 2.14 and 1.68, respectively, were obtained. Stirring the suspension during the determination when the electrode was in the supernatant liquid resulted in a considerable depression in the pH value obtained. A little of the washed permutite placed on the tip of the tongue gave a distinct acid taste.

The results which have been obtained in these studies agree quite closely with the theory expressed by Page (10) to describe the nature

of the alumino-silicic acids and their behavior in soil acidity given in his excellent review of theories on soil acidity.

SPEED OF REACTION OF ALUMINO-SILICIC ACIDS

The sample of artificially prepared zeolite which was used in the previously described experiments gave what was presumably the free alumino-silicic acid, when leached with 0.05 N hydrochloric acid. To prove that the acid as formed could again absorb base to give the alumino-silicate, a 1-gram sample of the acid was suspended in water and titrated with 0.04 N calcium hydroxide solution. Phenolphthalein was used as indicator. This sample of acid required, theoretically, about 85 cc of the alkali for complete neutralization. The first additions of alkali were very rapidly absorbed and neutralized by the alumino-silicic acids, but after 30 cc of alkali had been added, the rate of neutralization was considerably reduced and further reaction was delayed. The speed of the reaction was governed presumably by the speed of diffusion of the solution within the coarser acid particles and the reduction in the amount of replaceable hydrogen as neutralization proceeded.

This was demonstrated by the following experiment. A 1-gram sample of the acid was suspended in a solution containing 2.5 grams of calcium acetate and titrated with calcium hydroxide solution as before. The speed of the reaction was considerably increased, and the acid readily absorbed 78 cc of the alkali solution before the solution showed the permanent pink color of the indicator. In the latter stages of the reaction, gentle warming was found to hasten the reaction. This was probably instrumental in aiding the diffusion process. The titration required about 10 minutes for completion.

COMPOSITION OF ALUMINO-SILICIC ACIDS

A small quantity of alumino-silicic acid in the pure form was obtained from the hydrochloric acid leached permutite. Two liters of a clear extract of this material obtained by filtering through paper were evaporated to dryness. The residue was fused with sodium carbonate and analyzed for silica and alumina. This gave 0.0250 gram of SiO_2 and 0.0075 gram of Al_2O_3.

These figures represent a ratio of SiO_2 to Al_2O_3 of 6.6 to 1. Now, the alumino-silicic acid of the artificial zeolite possessed the composition $Al_2O_3 \cdot 6SiO_2 \cdot 6H_2O$. It would seem, then, that the alumino-silicate active in the exchange reactions of each of these materials was that with 6 molecules of SiO_2 to 1 of Al_2O_3. It has been previously stated that the chief constituent of the permutite was glauconite, but the results obtained in this work would indicate that

glauconite is not the mineral active in the exchange reaction. In further support of this contention, it might be remarked that the total base absorption capacity of the permutite was but 25.6 milli-equivalents per 100 grams, or about what would be expected of a mixture containing less than 10% of active zeolite.

That the active silicate is the same in both samples is indicated, also, by the value of the equilibrium K obtained in the study of the exchange reactions. For permutite, K = 2.6, and for the precipitated hexa-silicate, K = 2.9. The similarity of these results from widely different materials suggests the possibility that the secondary soil alumino-silicic acids may be rather limited in number. A determination of the equilibrium constants for the mineral portions of a series of soils would throw some light on this possibility.

That these acids behave in their reactions in the manner described is in perfect harmony with the theory which was found to describe the base exchange phenomenon. Even the zeolites themselves, which possess the base exchange capacity, though highly crystalline in nature, deport themselves as though highly colloidal in the sense that they offer such a high degree of internal reacting surface to the extracting solution. A suspension of the coarse acid material does not display the high degree of acidity of which it is capable, for the surface of contact between the particles of acid and the electrode is insignificant as compared with that presented by the same material in the finely divided condition.

NATURE OF ACIDS IN SOIL SOLUTION

When the pH values of soils obtained potentiometrically and colorimetrically are compared, fairly good agreement is usually found. But at times discrepancies have been observed and these have not been accounted for satisfactorily. The nature of the alumino-silicic acids would lead one to expect that an aqueous extract, if quite free from colloidal material, would possess a reaction identical with that of the water employed. Why, then, are the pH values as determined, by the measurements made on the filtered extract and on the suspension so often in excellent agreement?

The key to the situation involves a consideration of the salts dissolved in the soil moisture. The soil solution contains, in general, sulfates, nitrates, and chlorides of calcium, magnesium, sodium, and potassium. The soil also contains the corresponding alumino-silicates of these bases in the solid phase, and, if the soil is acid, there is also present the free alumino-silicic acids. The considerations involved in the equilibrium studies for hydrogen-ions and calcium-ions, as

previously discussed, require that an equilibrium exist between these anions and their alumino-silicates. There will necessarily exist in the soil solution of an acid soil a greater or less concentration of free nitric, sulfuric, and hydrochloric acids. The amount of each present depends on both the abundance of salts of these acids in the soil solution and the relative amounts of alumino-silicates and free alumino-silicic acid in the solid phase.

If a soil supplied in this way with soluble salts be taken and its pH value determined by the potentiometric and colorimetric methods, the results will represent the hydrogen-ion concentration due to the strongly dissociated soluble acids. That this value will be indicative, in a general way, of the proportion and kind of free alumino-silicic acid in the soil is apparent. But it must be appreciated that the reaction involved is specific in its nature and depends on the proportion and kinds of salts present, as well as on the nature of the alumino-silicic acid or acids present in the soil.

The partial dependence of the pH value of a soil extract on these strong acids in low concentration is substantiated by the results of Pierre (12), who found that soil as taken from the field often gave pH values, determined colorimetrically, which varied with the ratio of soil to water used in the determination. He also found that leaching of the soil with water often resulted in an elevation of the pH value due to the removal of the soluble acids and salts and that, after leaching, dilutions varying between 1 to 2 and 1 to 50 had no influence on the pH value of the extract. This constant value, which lay between 5.0 and 5.6 for the soils investigated, is probably due to the true solution of the alumino-silicic acids, or possibly, organic acids of the soil.

A soil which is low in soluble salt content would be expected to lead to discrepancies in the pH values, depending on the method of determination. This would apply to soils which have been subjected to excessive leaching or to those which have been sampled following a heavy rain.

The process of electrodialysis as described by Mattson (8) gives further confirmation of the colloidal nature of the alumino-silicic acids. Although the entire amount of replaceable bases may be obtained in the cathode compartment, the only anions found are those of nitric, sulfuric, and phosphoric acids. The alumino-silicic acid "ions" do not pass through the parchment membrane. The residue in the central compartment of the cell will, at times, develop a low pH value as measured electrometrically; but when tested by the dialysis method, the dialysate shows no change in the hydrogen-ion concentration of the conductivity water employed.

SIMILARITY OF OLEIC, STEARIC, AND TUNGSTIC ACIDS TO SOIL ACIDS

In the foregoing studies of the exchange reaction, it has been shown that the theory as outlined represented fairly well the facts observed for the zeolites and the soil exchange complex. It might be expected that this reaction mechanism is more general in its scope than has been hitherto considered. A well-known reaction which is suggestive in this regard is that involving the precipitation of insoluble calcium and magnesium oleates and stearates from the solutions of sodium salts of these acids. The free acids are insoluble oils, and although they differ in many ways from the alumino-silicic acids, they have many properties in common. Thus, they react readily with sodium hydroxide solutions to give highly colloidal dispersions. In the form of the calcium and magnesium salts they are completely flocculated, particularly as the calcium compounds. An attempt was made to determine the equilibrium relationships between calcium and magnesium oleates. The results were not altogether satisfactory by reason of the difficulty in obtaining the pure oleate in the colloidally dispersed conditions, and the high value of the constant K which seemed to be in the vicinity of 15.

When free oleic acid is shaken with a solution of calcium acetate, the liberation of acetic acid in the solution is readily demonstrated. This is quite analogous to the behavior displayed by an acid soil.

The difficulty in obtaining a stable colloidal suspension of oleic acid precludes the possibility of determining its pH value under these conditions. That other insoluble acids in the colloidal state may exert a considerable hydrogen-ion concentration is shown by the suspensions of tungstic acid. Different proportions of acid to water gave the following pH values·

Grams acid per 25 cc suspension	pH value
0.5 gram	4.10
1.0 gram	3.02
1.5 grams	3.72
3.0 grams	3.58

The tungstic acid also exhibited a behavior similar to that shown by alumino-silicic acid when a suspension was titrated with calcium hydroxide solution. The reaction proceeded rapidly in the early stages, but the rate fell off as the finest particles were neutralized and diffusion within the coarser particles became a limiting factor. Heating and the addition of calcium acetate to the suspension accelerated the reaction very considerably.

SUMMARY

The great speed of the base exchange reaction of soils led Gedroiz to disfavor the idea that it is a chemical reaction. It was found, however, that the exchange reaction of crystalline zeolites is particularly rapid, and that in the reaction, the crystalline nature suffers little or no change. This necessitates a comparatively open structure in order that the cations in solution may be exchanged for those in the space lattice of the crystal. It seemed reasonable to believe that the great speed of the exchange reactions of soils could also be explained as due to the open structure or colloidal nature of the exchange complex involved, and on this purely chemical basis a mass action equation for the heterogeneous equilibria was formulated. This equation was applied to the data obtained in base exchange experiments and was found to describe fairly accurately the results obtained. Because of the open structure or colloidal nature of the compounds involved, it was necessary in formulating the equation to recognize that the active masses of exchange complexes varies as the exchange reaction proceeds.

In the case of the natural and artificial zeolites, the same mass action equation was found to apply in describing the mechanism involved These substances are undoubtedly definite chemical compounds of characteristic crystalline form, and the fact that they behave in the same manner as do natural soils offers strong evidence for the purely chemical nature of the base-retention phenomena displayed by the soil. The adsorption theory seems quite inadequate to explain the phenomena observed.

The organic matter of soils was found to possess a high base exchange capacity. Due undoubtedly to the colloidal nature of the organic matter, the same mass action equation was again found to apply.

Evidence was adduced in support of the presence of zeolitic materials in the soil. An examination of the silt from one soil revealed the presence of the mineral leverrierite, a hydrated alumino-silicate which possesses the power of base exchange.

From the natural and artificial zeolites tested the free aluminosilicic acids were prepared. These were colloidal in nature, and possessed an interesting series of properties, analogous to those displayed by acid mineral soils. The colloidal acid was insoluble and non-diffusible, and yet in an aqueous suspension pH values as low as 1.68 were recorded. The hydrogen-ion concentrations of the suspensions were approximately proportional to the amounts of solid material in suspension. Thus, acids need not be in true solution in

order to give rise to acid pH values when determinations are made electrometrically.

On the basis of these properties of the colloidal alumino-silicic acids, many seeming anomalies which have been recorded in soil acidity studies are readily explicable. The effect of the soil-water ratio, differences between the pH values for suspensions and filtrates, and many other difficulties are cleared up.

That this type of reaction, as exemplified by the zeolites and soils studied, is not uncommon, is suggested. Insoluble colloidal acids like stearic and tungstic have been shown to behave in pH studies, and in their neutralization reactions, in a manner perfectly analogous to the alumino-silicic acids.

All these studies emphasize the fact that the difference between the chemical behavior of materials in the colloidal state and those in true solution is one of degree only and not of kind. The colloidal material may take part in reactions governed by the stoichiometric laws for metathetical reactions, and may be regarded as displaying ionization phenomena in a manner quite analogous to that of dissolved substances.

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CROP ECOLOGY AND ECOLOGICAL CROP GEOGRAPHY IN THE AGRONOMIC CURRICULUM[1]

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INTRODUCTION

Crop ecology is a comparatively recent addition to the curricula of as yet but a limited number of institutions. Only five institutions at the present time offer definite courses in this subject and in two of these, in the Michigan State College and in the University of Wisconsin, it is offered to graduate students only. The University of Illinois, the Kansas State Agricultural College, and the Oklahoma Agricultural and Mechanical College are the only institutions in the United States at the present time offering courses in crop ecology to undergraduate students. In Canada, the Ontario Agricultural College offers crop ecology to undergraduates. Some institutions, such as the Agricultural College of Utah, offer courses in the geography of agriculture, either in the agronomy or in the economics departments. Such courses may include many of the topics to be outlined for crop ecology and ecological crop geography as may also courses in agricultural meteorology. No doubt many of the factors to be outlined may be made use of in the teaching of agronomic subjects even where distinct crop ecology courses may not at present be organized.

It is the object of this paper to outline the scope of crop ecology and ecological crop geography and to point out what factors may be considered in such a course.

SCOPE OF CROP ECOLOGY AND ECOLOGICAL CROP GEOGRAPHY

Agronomy, as stated by Ball (1),[3] is the "Art and Science of Field Crop Culture." The agronomist and especially the producer who offers his crops to a competitive market is, however, concerned with far more than that. He is interested as much, if not more, in the distribution, the acreage devoted to a crop, the cost of production on the part of competitive growers, and the final utilization of an agricultural commodity, as in its original production. All these factors determine whether or not he may successfully produce a certain crop.

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[3]Reference by number is to "Literature Cited," p. 352.

In other words, the agronomist is called upon to deal with the actual production of a crop and at the same time with its ultimate utilization, he must keep in mind the physiological as well as the economic and social forces encountered in his task of enlightening the public and more particularly the student in his chosen field.

Crop producers have, from time to time, suffered heavy financial reverses due to their lack of knowledge of the economic forces met with in the production and utilization of their products. Every student of geography is aware of the fact that centers of crop production are determined in part by economic forces such as demand, facilities for, cost of transportation, various labor problems, and competition. For instance, there is a close correlation between the centers of potato production and the world centers of population, while wheat, a comparatively non-perishable crop, is mostly grown distant from such centers of population. In many cases an improvement in the prevailing systems of transportation may throw two rather remote sections into active competition. This applies within a given country especially in the competitive production of rather specialized products as well as in the world wide production of specialized but more particularly the ordinary food products.

The cost and the availability of labor is a potent factor in determining cropping centers. High priced labor is best employed on land adapted to the production of high yields of specialized crops. To do this it is necessary to have favorable climatic and soil conditions, especially the former, since man can do little to alter them whereas he has numerous methods at his command for improving the soil conditions, providing that the prevailing climatic conditions allow their utilization. Thus, a crop rotation providing for the upkeep of nitrogen and the organic content of the soil is easily outlined and employed in the humid sections of the United States but offers almost insurmountable difficulties in the semi-arid and arid sections of the country.

Kzymowski (20) illustrates graphically that the greatest intensity of labor and capital is most profitably employed in the production of a relatively high priced product on a fertile soil. On all the continents intensive systems of agriculture prevail in sections near the centers of population and consequent higher net prices, and where favorable climatic and soil conditions predominate.

Economic conditions as such and as they influence social conditions and the purchasing powers of a people have also an important bearing on crop distribution, especially when world distribution is considered. These factors determine in the main the standards

of living found. In some instances, a crop is produced and assumes a place of importance above all others due simply to the fact that it yields a greater amount of total food material per unit of area. The Chinese and the orientals as a whole subsist, to a large degree, on vegetable foods, the economic conditions and pressure for food being such that the bulk of the population cannot afford a meat diet. Prevailing social conditions not only influence the distribution but also the method of handling a crop, *viz.*, the methods employed in the production of cotton in the various sections of the southern states or the methods in use in the production of the sugar beet in its wide region of adaptation.

Climate constitutes without doubt the greatest factor determining the location of cropping centers. Climate, also, as brought out by Huntington and Cushing (14), Huntington (15), Olbricht (22), and by Taylor (31), is one of the main factors, if not the most important factor, determining world centers of population.

A discussion of the relationship of climatic factors leads to the employment of a term much used by ecologists, namely, "habitat." This term was used originally in the sense of describing the place in which a plant lives. Tansley (30) defines habitat as "The sum total of effective conditions under which a plant or community lives." Fitting (10) has the same conception, speaking of habitat (Standort) as "Die Gesamtheit der Umweltsfactoren eines Organismus."

Plants may have either a narrow or a wide range of adaptation. That is, they may be very exacting in their requirements of the environment and therefore be limited in their distribution, or they may have a great tolerance to factors working either in excess or lacking in intensity. The distribution of some plants may be limited not because of this condition but for the reason that conditions were adverse to migration. It is, necessary therefore, to distinguish between an actual and a potential habitat. The distribution of the sorghums was greatly furthered by man taking a part in aiding their migration. This was also true with such important cultivated plants as corn, wheat, tobacco, rice, the potato, and to some degree all crop plants since they became objects of world trade. Much of agronomic experimentation, in the last analysis, is a test designed to find the limits of the potential habitats of crop plants.

Plants to be adapted to a certain region must have a cycle of development which is in harmony with the factors of the environment. Some plants, such as corn in the northern states, did not in the beginning exhibit this required association. The cycle of development of the corn plant was, however, plastic enough so as to fit into the

habitat. There was in these northern sections a need for early maturing, more frost resisting, more often frost escaping plants. The introduction of the hard red winter wheats and of the durum wheats has done much to move the limits of wheat production into the western and more arid sections of the United States. The breeding of Marquis and other early maturing varieties of wheat in Canada has done much to move the limits of wheat production to the north. But for the plasticity of the wheat plant, the plains of Canada would not today produce 10% of the world's wheat crop

Attempts to grow crop plants beyond the limits of their potential habitats have resulted in great losses to private enterprise as well as in great damage to the public domain. Many of the marginal lands of humid regions should, for their best utilization, have been allowed to retain their natural vegetation rather than to have been put under cultivation. High, often abnormal, prices of agricultural products prevailing for but short periods played a prominent part in divesting such marginal lands of their natural protective coverings. In semi-arid regions, lands either too shallow, too light, or lacking in permeability for the sufficient storage of moisture have in past years been broken up without regard for the future. Such lands were often farmed for but a short time till it became evident that crops could not be grown on them with profit. They were then allowed to lay idle and to waste away. In regions with a typical grassland climate, the predominating native grasses show a most remarkable degree of adaptation to the prevailing climatic factors and often to those factors limiting crop production, such as lack of moisture together with a high rate of evaporation. Lands approaching the limits of the potential habitat should not be devoted to the production of crop plants. The natural vegetation, such as timber or grass, will yield better and more certain returns at least till such time when these lands may be forced into the production of specialized crops by economic demand.

According to Tansley, the main factors of the habitat fall into four classes, namely, (a) climatic, (b) physiographic, (c) edaphic, and (d) biotic.

CLIMATIC FACTORS

The climatic factors are many. Since their effects are interrelated, the influence of any specific factor must be considered in the light of the others. The main climatic factors are temperature, moisture, and light. Of less importance are atmospheric pressure and air currents. Superimposed on these but not of less importance is periodicity.

The interpretation of climatic data necessitates a knowledge of seasonal variations. Information on the periodicity of climatic phenomena may, at times or in certain regions, be of far greater value than mere averages. A section may have a high annual rainfall, yet be quite dry at a time of the year when plants may be in special need of moisture. Or the average temperature of a region may be neither too high nor too low, but may at times exceed a maximum or drop below a certain minimum and thus limit plant production or at least modify the cropping system to be adopted.

Periodic climatic manifestations leave a lasting impression on natural vegetation and in like degree have a great influence on the selection of crop plants. As brought out by Hildebrandt (13) uniform climates are conducive to the development of perennial types of vegetation, while climates with marked perodic changes give rise to annual plants. In arid and semi-arid regions, many plants take advantage of the fact that seeds are less susceptible to unfavorable climatic conditions than vegetative organs. Consequently, the plants found are either annuals or else are protected from damage during periods of extreme drought by special morphological, structural, or physiological characteristics. The development of such protective characteristics, however, is not confined to the perennial crop plants encountered but may be exhibited also in the annuals and especially in winter-annuals such as winter wheat, as shown by Klages (17).

Periodicity of climatic factors, especially with regard to moisture, has a decided effect on crop distribution. In sections where periodic dry periods are the rule, annuals spring up and grow rapidly in an attempt to complete their cycles of development during the relatively short period when moisture may be available. Perennial crop plants, such as the meadow grasses and the true clovers, predominate in regions having a comparatively uniform distribution of rainfall. The forage plants grown in the eastern humid part of the United States, such as timothy, redtop, and the clovers, are perennials requiring a relatively abundant supply of moisture. In the northern Great Plains area, on the other hand, a large number of annual forage plants, such as the millets, Sudan grass, and early varieties of sorghums, are encountered. In the central and southern Great Plains area, especially in the short grass sections, annual plants assume even a greater importance than to the north. The reason for this distribution is quite apparent in the light of what has been said. Alfalfa, while being the dominant forage crop of the western states, is limited largely to the "tall grass and mixed prairie" where the subsoil is still more or less moist, as brought out by Weaver (36), and to the irri-

gated sections. It and sweet clover are grown in the more favorable part of the annual forage section of the Great Plains area because of their extensive root systems and due to their ability to endure the at times high temperature.

Chillcott (5) in his investigations on "the relations between crop yields and precipitation in the Great Plains area" came to the conclusion that, "Notwithstanding the fact that annual precipitation is a vital factor in determining crop yields, it is seldom, if ever, the dominant factor; but the limitation of crop yield is most frequently due to the operation of one or of several inhibiting factors other than shortage of rainfall." This conclusion bears out the fact that the specific influences of climatic and edaphic factors are interrelated. The investigations on which this far-reaching statement is based may be criticised from the standpoint that no attention has been given to the economy of water utilization of the crop plants discussed. This is a vital factor to be taken into consideration. Moisture, for instance, that falls on the ground only to run off rapidly in the extremely heavy rains which are quite common in the southern Great Plains area cannot be expected to be of great benefit to plant life. This is also the case with moisture which may fall on the soil only to evaporate within a short period of time.

Of the four factors of the habitat enumerated the climatic factors are, no doubt, of greatest importance in so far as they directly influence all the others. The physiography of a region, the soil conditions, as well as the fauna and flora are directly influenced by the climate. In turn, the climate may be modified to a considerable degree by topography and related factors. As stated by Spafford (29), "The boundaries of the four great agricultural regions in the northern hemisphere are determined by low temperature, low rainfall, and coast line. In southern Canada, Norway, Sweden, and Finland, and in northern Russia, Manchuria, and Japan, agriculture is limited by low temperature. The principal agricultural boundaries determined by low rainfall in North America are found (a) in the states of the Great Plains and (b) in the states of the Pacific Coast region. In Eurasia, the principal agricultural boundaries determined by low rainfall are found (a) in southeastern Russia and (b) in western China proper and Manchuria."

PHYSIOGRAPHIC FACTORS

The physiographic factors may be classified as (a) the nature of the geologic strata, (b) the topography, and (c) the altitude.

In relation to soil formation, the nature of the geologic strata may be considered as an edaphic factor. It is a physiographic factor in so

far as it is active in accounting for a given topography. Here again it becomes evident that the factors of the habitat are closely interrelated. As brought out by Shantz and Marbut (27), soil is formed by a joint action of climate and vegetation features. While the original material from which soil is formed is of importance, it must be recognized that identical parent rock under varying climatic conditions will give rise to soils of greatly differing physical and chemical properties.

Topography is a great factor determining climate. General topography, direction of main mountain ranges to prevailing winds, and large bodies of water are important from the standpoint of determining precipitation and temperature. It, together with the nature

TABLE 1.—*Rates of evaporation from Livingston's cup atmometers in different locations, Stillwater, Okla.*

Dates	Upland exposed grass meadow	Bottomland grass meadow	Sweet clover on upland	Cotton on upland	Red kafir on upland
May 28 to June 4...	332	271	300	266	296
June 4 to June 11. .	473	340	385	543	510
June 11 to June 18..	394	286	234	453	375
June 18 to June 25..	295	217	275	360	261
June 25 to July 2. .	378	261	328	426	286
July 2 to July 9.	489	330	442	541	342
July 9 to July 16 .	289	196	228	237	164
July 16 to July 23	363	244	305	342	228
Total...	3,013	2,145	2,497	3,168	2,462

of the geologic strata, is a factor in determining the natural drainage of a region.

Topography has a great influence on local climate. It may serve to protect an area from excessive evaporation or it may serve to modify the temperature to a marked degree. In Table 1 is given a tabulation of the rates of evaporation as recorded by Livingston's cup atmometers at Stillwater, Okla. The loss of water for five locations is given, namely, (a) on an exposed upland native grass meadow, (b) on a bottomland native grass meadow 200 feet from location (a) and approximately 30 feet lower, (c) in a sweet clover field sown April 1, (d) in an upland cotton field, and (e) in a field of Red kafir. In the first four locations, the vegetation did not extend above the at-

mometer cups. The kafir leaves reached a greater height than the atmometer cups after the third week.

The rate of evaporation from the atmometers placed in the cotton was high, due to the fact that the ground was not shaded. The same is true for the evaporation in the kafir before the plants shaded the ground. The difference in the rates of evaporation on the exposed

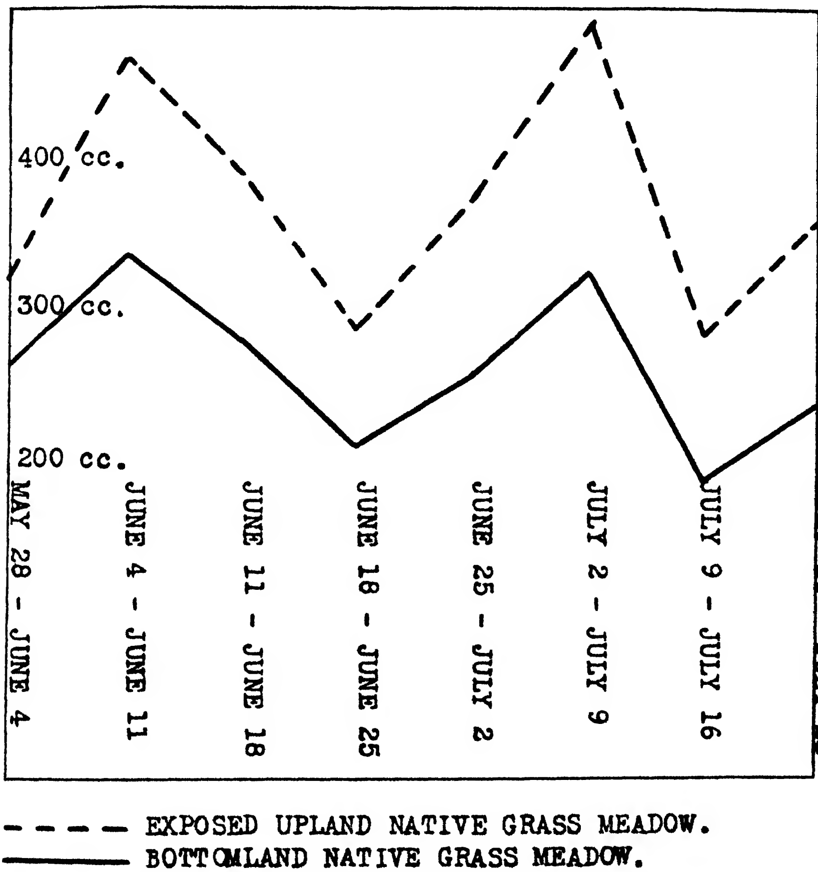

FIG. 1.—Showing differences in loss of water from Livingston's cup atmometers in an exposed upland and bottomland native grass meadow, Stillwater, Okla.

native grass meadow and in the bottom (Fig. 1), is accounted for by differences in exposure. Attention is called to the fact that the differences in the loss of water from the atmometers on the exposed upland and more or less protected bottomland native grass meadow are accentuated during the weeks of high evaporation, June 4 to June 11, and July 2 to July 9. Such periods of maximum activity of a factor of the environment calling forth an active and not often a maximum

response of particular functions of the plant have a special significance to plant and crop distribution and the determination of the potential habitat.

EDAPHIC FACTORS

The soil is one of the most important factors of the habitat. This is true especially in studies limited to a given locus. Climatic factors are spoken of as being regional, while soil factors are local or, as Spafford speaks of it, "Soil effects are often submerged by climate." Schimper (26) speaks of climatic and edaphic formations. Tansley, taken from Waterman (34), criticises the term climatic formations from the standpoint that, "Nothing like a sharp line can be drawn between one climatic region and another so that it becomes impossible to delimit climatic formations." While it is true that one type of vegetation gradually shades into another in a transitional region, just as one agricultural province or cropping area grades into another without a distinct boundary between them, it is also true that the climates of the world may be grouped into a relatively small number of classes each of which affects a large region. Within such larger regions, soil variations play a prominent part in determining the agricultural utilization of particular areas. As stated by Schimper, "Every climatic district exhibits, besides the corresponding oecological type of vegetation, one of the two other types in certain localities because the properties of certain kinds of soil weaken or strengthen the influence of climate."

BIOTIC FACTORS

Much may be said of the last general factor of the habitat, namely, the biotic factor. Under the biotic factor are considered the effects of other organisms, either plants or forms of animal life. The associates of a habitat may be either helpful or harmful. There are symbiotic as well as parasitic relationships. In limiting this phase of the discussion to crop plants, the effects of plants growing in a rotation, the micro-flora of the soil, the effects of parasites, and the effects of domesticated animals must be considered. The personal equation of the producer is, however, the predominating factor in so far as he has at his command methods and means of altering the factors enumerated.

CROP ECOLOGY AND ECOLOGICAL CROP GEOGRAPHY DEFINED

The botanist or plant ecologist defines ecology as the study of plants in relation to their environment. The plant ecologist is concerned mainly with the habitat of the plant and association of plants and, it may be said, with the physiology of the plant or group of

plants in a given environment. Investigations in plant physiology, more than any other branch of research, demonstrate and lead to a better understanding of the complex relationships of a plant to its environment. Some agronomists may say that such investigations lie in the field of botany. The investigator, to have definite understanding of the relationship of a crop to its environment, must keep in mind both the botanical, more directly the physiological, and the agronomic aspects of the situation.

Crop ecology may be defined as the study of crop plants in relation to their physiological environment. Ecological crop geography, on the other hand, dealing with the broad distribution of crops and with the underlying reasons for such distributions, is concerned with more than the physiological environment. The ecological crop geographer is concerned with more than the direct relationship of the plants he is dealing with to their environment. He must consider the points taken into account by the crop ecologist and in addition must recognize the operation of economic, political, historical, and social forces. Thus, ecological crop geography may be defined as the study of crop plants in relation to their physiological and social environment. By social environment, is meant the aggregate impress of economic, political, social, and historic forces. A discussion of the social environment does not enter into the study of crop ecology as such, but for the sake of completeness and in view of the fact that the agronomist is ever interested in the world distribution of crops it is well to treat crop ecology and ecological crop geography together. Prejudice on the part of the producer or a well established market demand or practise may account for the occurrence of certain crops in a section or for the methods in use for the handling of a crop. As an illustration of the first condition, the place of timothy as a market hay in the northeastern portion of the United States may be referred to. The method of handling grain in sacks rather than in bulk which has so long been a practise in the Pacific Northwest gives an example of the second condition.

Ecological plant geography, put on a firm basis by the work of such men as von Humboldt, Schouw, Meyen, Griesebach, Drude, Schimper, and Warming, has a very direct bearing on the subject under consideration. A. von Humboldt may, with right, be called the father of plant geography. He gave a preliminary outline of the problems involved in his work "Ideen zu Einer Physiognomik der Gewächse" in 1806. His work was followed by that of Schouw's "Grundzüge Einer Allgemeinen Pflanzengeographie" in 1836. These were followed by the well-known works of De Candolle's "Géographie botanique

raisonnée" 1856, Griesebach's "Die Vegetation der Erde" in 1872, and by the better-known publications of Drude (7) Schimper (26), Warming (35), Clements (6), and Livingston and Shreve (23).

Warming speaks of floristic and ecological plant geography. Floristic plant geography treats the compilation of "floras" and the division of areas into natural "floristic tracts," together with a discussion of the limits of the species, genera, and families encountered. Ecological plant geography deals with the underlying causes of how plant communities adjust their forms and modes of behavior to the ecological factors of their environment, such as the amount of available heat, light, water, nutrients, etc. The physiognomy of a vegetation is determined not only by the mode of reaction of individual species to environmental factors, but to a greater extent by the joint response of all species found in a habitat and the consequent grouping and existence or competition, as the case may be, of various species in communities, associations, or formations. It is the task of the ecological plant geographer to investigate the principles along which these groupings proceed, exist, or at times change, that is, to determine the trend of plant succession and the development of climax vegetations for given regions

Crop ecology differs from the study of crop statistics as ecological plant geography differs from floristic plant geography. Crop statistics are indeed of value to the ecological crop geographer as are floras to the botanist or plant ecologist. His task, however, involves more than the compilation of figures showing distribution The crop ecologist is concerned especially with the reasons for such distributions, with the grouping of separate crops and the resulting systems of cropping practised, as well as with the competition found to exist between certain crops. But, above all, crop ecology is concerned with the study of adaptation or, as Warming speaks of it, the "epharmony" of crop plants. Only through comprehensive investigations of the requirements exacted by various crop plants of their environment can progress in the improvement of these plants be made with the minimum of effort and expense. Such requirements exacted may be of a physiological or economic nature. That is, workers in plant breeding should take into account such factors as quality and general conformation for which a market can rightfully pay a premium, as well as characteristics enabling greater economy in handling a crop and, what is often of far greater consequence to net returns, those properties of plants enabling them to escape or survive critical periods in their growth or enabling them to overcome limiting factors encountered in their culture.

The main ecological factors, such as moisture relationships, temperature relationships, light relationships, and the form and availability of nutrients, determine the physiological limits of crop production. All these factors are not only necessary for the normal development of plants, but they must again be taken into consideration in studies of abnormal manifestations of plant life. Plant pathologists are aware of the fact that disorders in plants, be they physiological or parasitic in nature, are either augmented or decreased in severity by the influence or factors of the environment, most frequently by climatic but also by edaphic factors.

SUBJECT MATTER TO BE TREATED IN THE CROP ECOLOGY AND ECOLOGICAL CROP GEOGRAPHY COURSE

An outline devised by one person is often of little value in the hands of another. The reader will not be burdened, therefore, with a detailed outline. The purpose of this paper is to show the possibilities of a course in crop ecology and ecological crop geography and to bring out the essential points that the writer deems wise to be included in such a course.

No course in crop ecology can be complete without a discussion of the main factors of the habitat as brought out in the first part of this paper

The discussion of the climatic factors leads at once to a consideration of the fundamentals of meteorology. A whole semester, of course, could be devoted to this field alone, but it will suffice to take up the climatic conditions in the main cropping centers of the world as treated in Eckardt's (9) recent publication on the physioclimatology of the continents. This will obviously lead to a discussion of the various manifestations of climatic phenomena, Ward (33). A classification of the climates of the world as attempted by various plant ecologists, geographers, and climatologists may well be considered. Thus, Warming classifies the climates on the basis of moisture available to plants, De Candolle on the basis of temperature, De Martonne, cited by Drude (7), on the basis of both available moisture and temperature, Jones and Whittlesley (16) on the basis of precipitation and relative location, Drude on the basis of periodicity, Schimper on the basis of natural vegetation, and Hann (11) and Smith (28) on the basis of relative location. At this point good use can be made of Visher's (32) book on climatic laws.

Taking up Schimper's classification of the climates on the basis of natural vegetation, leads to the interesting topic of the utilization of the natural vegetation as an index to the agricultural possibilities of a region. The student should be given an opportunity to become

familiar with the main formations prevailing in the crop-producing centers of the United States and of the world. This will lead to the solution of such problems as, what kind of economic plants can be expected to flourish in the woodland climates of the temperate zone? In the woodland climates of the torrid zone? In the desert and grassland climates of these two zones? Or on the Savannas of the tropics? Weaver's (36) recent paper will be found interesting along this line.

The effects of the geologic strata, topography, and altitude on crop distribution find a place for discussion under the physiographic factors. A discussion of the physiographic factors, especially if taken up in connection with the climatic factors, leads to a consideration of various modifications of soil conditions, the edaphic factors. To what extent is crop production limited by such factors as soil reaction or the physical and chemical composition of the substratum? That is only one of the unlimited number of questions that may arise under the discussion of this phase. The relationship of the edaphic factors to crop distribution may well be taken up in the crop ecology course without danger of trespassing on soils courses offered in the curriculum.

A consideration of optima and limiting factors should be taken up while treating the general relationship of a crop to its environment. Such optima and limiting factors must be considered both from the physiological and social points of view. The producer is always interested in bringing about conditions so that each separate function of the plant may be at its harmonic optimum, using Schimper's terminology, and that conditions may approach the theoretical ecological optimum. Limiting factors to crop production offer fertile ground for discussion as do also critical periods and hazards encountered in the growth of plants. The breadth and possibilities of the field here opened are brought out by Blackman's (2) paper on "Optima and Limiting Factors" and by Harder's (12) criticism of this paper. The study of critical periods and hazards is, of course, intimately associated with the problem of crop insurance.

The possibilities of breeding plants to overcome or to escape critical periods encountered in their production and a discussion of the physiological limitations as related to the creation and the survival of plants or of strains of established crop plants offers a wide field for speculation. This touches on one of the greatest phases of agronomic research.

Another question to be considered in the relationship of a crop to its environment is that of adaptation. What are the points involved in adaptation? The question of adaptation may well be considered

from the standpoint of the degree of harmony exhibited between the "vegetation rhythm" and the "climate rhythm" as brought out so admirably by Scharfetter (25). A plant cannot adapt itself to a given region unless there exists some degree of harmony between its general cycle of development and the general course of meteorological phenomena. As stated by Lundegardh (21), one plant is better adapted than another in case it is able to economize to a greater degree the energy and nutrients available and is protected better against unfavorable factors. This calls for knowledge not only of the climatic conditions throughout the season, but also of the specific requirements of the plant during definite phases of its cycle of development. The response of a plant to ecological forces differs with each specific stage of development. The various requirements for each of these stages furnish ample room for discussion. This condition also leads to the much mooted question of variability in plants, to the possibilities of the development of physiological strains, and variability in response to factors of the environment or to Delto's "potentielle Variationsbreite," Klebs (18, 19).

The influences of the main ecological factors, such as moisture relationships, temperature relationships, and light relationships, on the distribution of the important crop plants should be taken up in detail. These factors, more than any others, determine the physiological limits of crop production.

But as stated earlier in the paper, the physiological environment is only one of the factors involved in the studies of ecological crop geography. The other is the social environment.

The student before taking the ecological crop geography course will have had courses in economics and will have an understanding of at least the fundamental economic laws. However, in courses of economics, unless the instructor has considerable knowledge of crop distribution, very little attention is often given to this important relationship. That economists are giving more thought to this question is shown by Buechel's (4) recent book. A general study of the growth of populations, of the factors making possible such phenomenal increases in population as were witnessed in the past century, and of the factors determining density of populations will lead to a better understanding of agricultural situations. For instance, such points as the more or less stable population during medieval times, the increase in population with the rise of commercialism and rise of national feeling, and the still greater increase and the building up of great centers of population as a direct result of the Industrial Revolution are factors of great importance to the de-

velopment of agriculture and to the economic aspects of crop production and distribution, according to East (8), Reuter (24), and Wright (37).

"Hunger and new ideas are two advocates of change which plead best in each others company; hunger makes men willing to act, and the new ideas give them matter for enactment." These words of Bonar (3) may be applied to the problems created by increasing population and less rapidly increasing supplies of available food. While pressure for the means of subsistence may often have stirred man to activity, it was by no means the only factor making for advance. As a matter of fact the time and energy of a people may be drawn upon to such an extent as greatly to interfere with advance and the furthering of culture traits. Yet, frequently the tree of prosperity has its roots in the soil of necessity. Increased population and with it increased pressure for food have in times past and will in the future lead to a more and more intensive study of the problems involved in the production and distribution of food products. Since this is the case, a brief consideration of the growth and demands of population merits the attention of the agricultural scientist. Political economists, sociologists, and students of eugenics in the main have dealt with the analysis of this problem, with the reasons underlying population increases, and with the checks operative in keeping the population of any region within certain confines. The researches of these men have been of great service in throwing light on the relation of the growth of population to environmental complexes. But the main fact is that populations have increased at a rapid rate, especially throughout the last century, and that this in itself has been one of the most potent factors leading up to the present standing of agriculture and agricultural science.

In times of necessity the cropping systems of the agricultural regions of the world may be altered materially. Thus, India the first country to have a sowing time after the outbreak of the world war, increased her wheat acreage by 4,000,000 acres. North America in 1915 sowed 12,000,000 more acres of wheat than normally. Australia added 3,000,000 acres. Thus, the inducement of higher prices increased the wheat growing area of the world by around 19,000,000 acres. After the close of the conflict, many of the producers found much to their sorrow that the purchasing countries were not in position to pay the price inflicted by forced production. The economic, social, and political factors directly or indirectly affecting crop production and distribution are too many to be enumerated here.

The relation of history to the present world distribution of crops opens an unlimited field and a field almost untouched by either historians or agriculturists.

WHEN SHOULD THE COURSE IN CROP ECOLOGY AND ECOLOGICAL CROP GEOGRAPHY BE OFFERED?

It is best to give the crop ecology course during the senior year. The course will then serve to give the student a well-rounded view of the agricultural situation. It should lead him to regard agriculture and agricultural development as a world industry rather than to regard it or be concerned with problems of local importance only. Above all, the course should be presented with the idea of being more than informational in nature, it should serve primarily to broaden the student's view point. A course of this nature should be of value not only to students in agronomy, but also to other agricultural students and to students in liberal arts and science courses and especially to students in economics. It would be a decided step towards advance if every undergraduate could be made to think of agriculture as a world industry. Jevons the English economist summed up the condition in an admirable fashion when as early as 1865 he wrote the following, "The plains of North America and Russia are our cornfields; Chicago and Odessa our granaries; Canada and the Baltic are our timber-forests; Australia contains our sheep-farms, and in Argentina and on the western prairies of North America are our herds of oxen; Peru sends her silver, and the gold of South Africa and Australia flows to London; the Hindus and the Chinese grow tea for us, and our sugar and spice plantations are in all the Indies. Spain and France are our vineyards, and the Mediterranean our fruit garden; and our cotton grounds, which for long have occupied the southern United States, are now being extended everywhere in the warm regions of the earth."

SUMMARY

At the present time only five institutions of the country offer definite courses in crop ecology and of these two offer it to graduate students only. This subject, together with ecological crop geography, merits more attention. The agronomic curriculum can be enriched by the addition of such a course. It is the purpose of this paper to demonstrate the possibilities of crop ecology and ecological crop geography, to show its application, and to point out the essential factors that in the estimation of the writer may be considered in the course.

The general scope of crop ecology and ecological crop geography is outlined.

Crop ecology may be defined as the study of crop plants in relation to their physiological environment.

Ecological crop geography may be defined as the study of crop plants in relation to their physiological and social environment. Under social environment is meant the aggregate impress of economic, political, social, and historic forces.

Crop ecology deals more directly with the physiological reactions of a plant to its physical environment, with such factors of the habitat as moisture, temperature, light, and composition of the substratum. Ecological crop geography treats the larger realm of crop distribution and is, therefore, concerned with the physiological as well as the social environment. A discussion of the social environment does not enter into the study of crop ecology as such, but for the sake of completeness and especially in view of the fact that the agronomist is ever interested in the world distribution of crops, it is well to treat crop ecology and ecological crop geography together.

A review of the literature cited, while making no claim for completeness, will show that a great wealth of material is available to be analyzed and synthesized.

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THE ATTERBERG CONSISTENCY CONSTANTS[1]

J. C. RUSSEL and F. M. WEHR[2]

Soil consistency as defined by Atterberg (3, p. 149)[3] is "The behavior of soil toward outside influences which can do work upon it, as the behavior toward gravity, pressure, thrust, pull, and toward the feel." It is the manifestation toward stresses of all kinds, of the physical forces of cohesion and adhesion acting within the soil mass, or between soil and other materials.

It is important to recognize that consistency varies with moisture content, and that any one soil has a wide variety of consistency manifestations, indeed almost an infinite number of quantitative expressions, as moisture content is varied from an unstable water suspension down to the oven-dry condition. The phenomena of consistency at various degrees of wetness are excellently described by Atterberg (2, p. 20) as follows:

"When one mixes clay in a powdered condition with much water, one gets a flowing clayey paste. With less water the paste becomes thick flowing. Through evaporation of the water, the clay goes over gradually into a tough, sticky mass that sticks to the fingers, wood, and metals. On account of the smeary, sticky condition the clay is not yet considered to be plastic. With further drying the stickiness disappears. The clay now can be easily molded without sticking to the fingers, and has now that which is required for 'normal consistency' for the clay-working industry and is recognized as plastic and 'just right for the hand.' With yet further drying out the formability comes finally to an end. The clay is indeed yet moist, the clay pieces can now, however, only be united by pressure to form a mass that hangs together. Finally it loses even this formability.

"The clay shows therefore at different water contents, very different properties. Sometimes they are flowing or half-flowing, sometimes they are sticky and smeary. Sometimes the clay will form well and roll out well, and sometimes it is only formable through pressure. Finally when the clay has completely dried out, it becomes firm and hard.

"Different clays show, however, not exactly the same properties. One clay continues sticky longer, another continues sticky only for a little while and becomes formable more readily. In order to be able to express these different properties in numbers one must seek for the limits (*per cent water content*) where these properties change."

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[2]Professor and former graduate student, respectively.

[3]Reference by number is to "Literature Cited," p. 372.

Atterberg recognized six principal consistency forms (3, p. 152) described as follows:

1. The thin-flowing consistency (*Dünn flüssige Konsistenz*).—In this consistency the soil is almost as easy flowing as water. The different soil particles are in suspension, and on account of their tendency to settle this consistency is unstable.

2. The thick-flowing consistency (*Dick flüssige Konsistenz*).—This form is to be recognized by its pasty-like consistency. Its upper limit is the water content at which the wet mass will just flow together leaving a distinguishable line of contact when a furrow is cut through it. The lower limit of this form is the upper limit of the following.

3. The tough-flowing consistency (*Zahflüssige Konsistenz*).—This form is recognized by its thick paste-like consistency. The upper limit is the wetness at which the soil in layers 1.5 cm thick shows no tendency to flow. The lower limit is identical with the upper limit of the following

4. The plastic consistency (*Plastische Konsistenz*).—This consistency is to be recognized by the ability to roll the soil out into a wire. The upper limit which Atterberg named the *Flieszgrenze* is the moisture content at which a V-shaped furrow in a cake of soil in a dish will just exhibit flowing at the bottom when assisted by violent jarring. The lower limit which Atterberg named the *Ausrollgrenze* is the wetness at which the soil can barely be rolled into a wire under the finger. The difference between the two limits of this consistency form is called the plasticity number (*Plastizitatzahl*). The plastic consistency is more sticky and less tough near the upper limit and less sticky and more tough as the lower limit is approached. Atterberg recognizes a "sticky limit" (*Klebegrenze*) or scouring point which is the wetness at which soil will barely scour on a nickle spatula. This limit usually falls at some wetness within the plastic range (2, p. 27).

5. The friable, firm consistency (*Losere feste Konsistenz*).—This is characterized by the tendency of the granules to hang together when lightly compressed, and to shrink on drying without entrance of air into the pores from which water is evaporated. Once enough water has been evaporated so that the film breaks between particles and air enters the pores, shrinkage apparently ceases, and the soil *looks dry* (9, p. 430).

6. The more hard, firm consistency (*Hártere feste Konsistenz*).—In this consistency the granules no longer hold together when lightly compressed, and no longer shrink on drying. But, when wet and molded, and then dried, the mass may be extremely hard and may require considerable force to break, or crush.

From the standpoint of soil tilth, the first three consistency forms are of minor importance as the degrees of wetness are beyond anything that would be found under tillage conditions. The upper and lower limits of plasticity, the plastic range, and the scouring point are important considerations.

In addition, it is desirable to know something concerning the properties of soil in its two firmer consistencies. Atterberg (3) has proposed two measurements of the latter, the *Zähigkeit*, or toughness-number, and the *Fertigkeitzahl*, or solidity-number, the first being the force required to cut standard briquettes at a wetness near to the lower limit of plasticity, and the second the force required to break standard briquettes when oven dry.

Atterberg investigated at length the details of the technic of the determination of his various consistency constants (2) and developed apparatus for the determination of toughness and solidity (3). He also investigated the question of the size of particles and the chemical substances or soil minerals which produce the phenomena of plasticity (5). The motive which impelled his investigation seems to have been his realization of the importance of the consideration of consistency in soil classification (1). In connection with his attempts at a classification of the soils of Sweden he made numerous consistency determinations (4, 6, 7).

Johannson (9), working under Atterberg's direction, investigated the toughness of soils at various degrees of wetness. Marquis (11) employed the Atterberg constants in studies on the tilth of certain marine and fluviatile soils of lower Germany, locally known as *Marschböden*. Kinnison (10) used certain of the Atterberg constants in a comparative study of the evaluation of industrial clays. Mitscherlich (12, p. 88) describes the Atterberg constants briefly in the fourth edition of *Bodenkunde fur Land- und Forstwirte*. The Atterberg methods have also been employed at the Rothamsted Experiment Station (8), and in the United States Department of Agriculture.

Wintermeyer (16) and Terzaghi (14) have investigated the procedure for the determination of the upper and lower limits of plasticity and the significance of these constants in the evaluation of soil as road-building material. These writers use the term "lower liquid limit," the free translation of *Flieszgrenze*, instead of the term "upper plastic limit" which is, according to Atterberg, the real significance of the *Flieszgrenze*. They also use the terms "coefficient of plasticity" and "plastic index" interchangeably with the term "plasticity number."

The authors' experiences with the Atterberg consistency constants began in 1922, since which date a great number of determinations have been made by Wehr (15) and Yoder (17) and in connection with other unpublished projects. Since 1923 the determination of Atterberg consistency constants has been a laboratory requirement in the course in soil physics at the Nebraska College of Agriculture.

The purpose of this paper is to show the reliability of the several Atterberg constants, to present the details of an improved piece of apparatus for the determination of toughness and solidity, and to discuss matters of procedure. The significance of the Atterberg constants in the evaluation of consistency and in the study of soil tilth problems is reserved for later publications. The determinations which will be discussed are as follows:

1. The upper plastic limit (*Flieszgrenze*)
2. The lower plastic limit (*Ausrollgrenze*)
3. The plasticity number (*Plastizitätzahl*)
4. The scouring point (*Klebegrenze*)
5. The toughness number (*Zähigkeit*)
6. The solidity number (*Festigkeitzahl*)

EXPERIMENTAL METHODS

The following are the methods for the determination of the several Atterberg constants as finally standardized in our laboratories. These methods do not differ essentially from the original methods of Atterberg, or from those described by Winterneyer (16), except that a different type of apparatus is shown for cutting and breaking soil briquettes. In all of these methods air-dry soil that has been ground in a mill to a fineness of about 0.25 mm is used except in the case of sandy soils which are ground to pass only a 0.5 mm sieve. In the case of gravelly or stony soils, material larger than 2 mm is usually discarded and determinations made on the "fine earth." Determinations are usually run in duplicate or triplicate. Small aluminum cans are used for the moisture determinations, weighings being made to the second decimal.

UPPER PLASTIC LIMIT

A 10- to 20-gram portion of soil is wet to a stiff paste with distilled water in a small round-bottom porcelain dish of 90 mm diameter, mixing being done with a stiff nickel spatula. The mass is removed from the dish, rolled and kneaded in the hands, and then tested in the following manner: It is smoothed into a round flat cake about 10 mm deep in the center of the dish and pressed tightly against the bottom. A clean wedge-shaped furrow is then made in the cake along one

radius, the furrow being about 10 mm wide at the top and 1 mm wide at the bottom. A heavy porcelain spatula pressed into the cake and worked back and forth makes a desirable furrow. The dish is then sharply and repeatedly struck against the heel of the hand in order to make the two segments flow together if they will. If the soil is too dry, more water is worked into it, and if too wet, more soil is added, until the mass when tested as above shows a bare tendency to run together at the bottom. The moisture content of the wet mass is then determined.

THE LOWER PLASTIC LIMIT

To a 10- to 20-gram portion of soil in a 90-mm porcelain dish is added distilled water a few drops at a time, mixing being done with the fingers, until the soil begins to lose its crumbly feel and to show a tendency to roll into wires between the thumb and finger. The mass is then removed from the dish, rolled and kneaded in the hands, and then tested in the following manner: Break off a small lump and carefully roll it under the finger on a piece of glazed paper so as to form a long wire if possible. If it rolls out too easily into a long limp wire that may break in long pieces, or not at all, it is too wet. If it crumbles under the finger and forms no wire at all it is too dry. It is just right when it barely rolls out into a wire that breaks into pieces ¼ to ⅜ inches long. If it is not at the right wetness, water or dry soil as the case may be is added until the proper moisture content is reached. The moisture content of the main wet mass is then determined.

Very stiff soils which cannot be manipulated satisfactorily in the hands may be worked by pounding with a metal hammer. Experience indicates that such a soil is very close to its lower plastic limit when it is barely formable into a cube.

THE PLASTICITY NUMBER

The difference between the upper and lower plastic limits is called the plasticity number. Sandy-textured soils have no lower plastic limit, that is they will not hang together and form a wire. They do, however, exhibit an upper plastic limit or rather a "lower limit of flow." The plasticity number of such soils is zero. On soils with very low plasticity numbers, the upper and lower limits must be carefully determined as it is easy to obtain a lower plastic limit figure which exceeds the upper in such cases. One should remember that he is seeking for the *lowest* plastic wetness, and with such soils should not attempt to form a wire of the wet soil but rather should adjust the wetness until a wire barely does *not* form.

THE SCOURING POINT

A 10- to 20-gram portion of soil in a clean 90-mm porcelain dish is gradually moistened with distilled water and mixed with a nickel spatula until it is wet enough to smear slightly on the sides of the dish. It is then kneaded into a compact cake and tested as follows: The spatula is cleaned, and then pressed tightly against a freshly exposed surface of the wet mass and drawn rapidly across it. If the spatula and the soil show polish, the soil is too dry; if the soil adheres to the spatula it is too wet. If too dry, water should be worked into the mass a few drops at a time testing after each addition until *one or two more drops* makes it distinctly too wet to scour. If it is too wet, considerable dry soil should be added and then the scouring point should be approached as above. When the wetness is reached at which one or two drops more water makes the soil distinctly too wet to scour, the moisture content of the mass is determined.

THE TOUGHNESS NUMBER

Weigh out into a large porcelain dish the air-dry equivalent of 160 to 180 grams of water-free soil. Add to this a quantity of water sufficient to bring the soil to a wetness 3% in excess of the lower limit of plasticity and work the soil into a uniform paste with a stiff nickel spatula or with the hands. Very heavy soils may be too stiff to work at the wetness specified, and 1 to 3 cc additional water may be added.

A 20 by 20 by 90 mm mold is next lined with paper, stood on a sheet of paper on a flat metal plate, and the wet soil packed into the mold, small portions at a time, with the finger. Care should be taken to pack uniformly along the edges of the mold as well as in the middle and to fuse each addition of soil into that already in place. When full, the extra soil should be trimmed off and the briquette smoothed on top and bottom. The briquette is then removed from the mold and placed under a bell jar until ready to use. Two briquettes should be made. None of the wet soil should be discarded but should be covered to prevent evaporation and saved for use later in the determination of the solidity number.

The apparatus used for determining the force required to cut wet briquettes, or break dry briquettes, is shown in Fig. 1. This apparatus was devised after several unsatisfactory attempts to improvise equipment like that used by Atterberg (3, p. 176–177). It can be constructed from equipment at hand in most any soil physics laboratory. It has given excellent satisfaction in the determination of all toughness numbers, also very good satisfaction in determination of solidity numbers up to a magnitude of 100 kilograms. It is not well adapted to solidity numbers beyond 100.

(A) is an ordinary solution balance with weight hanger removed, and a hook (B) from which to suspend either a light cloth bag (C) or a bucket (D) put in its place. Into the bag or bucket is run sand from a hopper (E) fixed directly above. Afterwards, the vessel and contents are weighed and multiplied by the factor 4.37 to get its force on the balance platform. (This leverage factor may vary with solution balances of different makes.) Over the platform of the balance is supported, in a very rigid manner as shown in the figure, a steel chisel

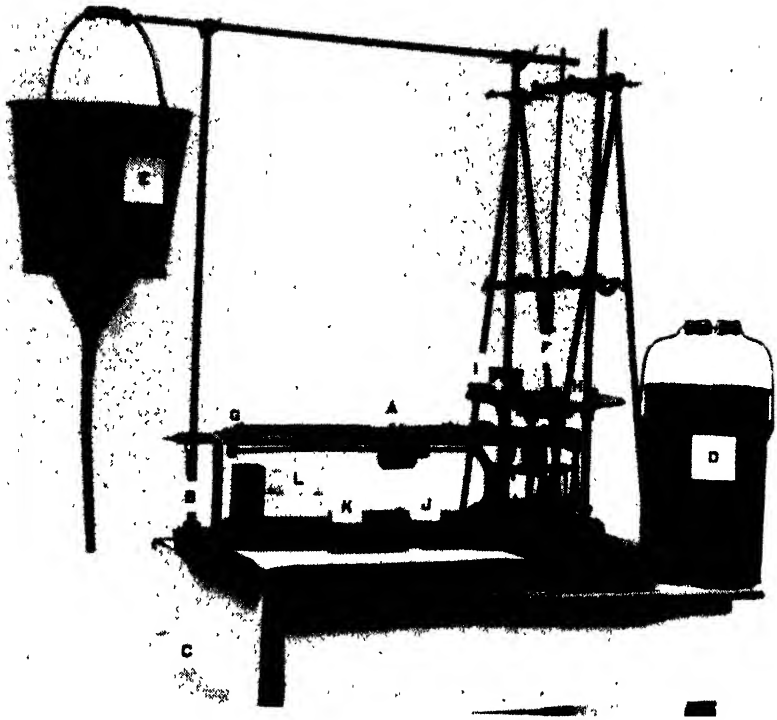

FIG. 1.—An apparatus for cutting and breaking soil briquettes.

(F). This chisel has a 15° cutting angle as specified by Atterberg (3, p. 175) and is kept polished and sharp. On the end of the beam of the balance is mounted a pointer (G) which moves along a scale calibrated so as to be equivalent to millimeters of movement of the balance platform. The pointer should stand at "5" on the scale when the beam is level. (H) is a prism which is placed on the platform directly under the chisel when the toughness number is being determined. (I) is a block carrying a steel 90° cutting edge which is placed on the platform beneath the chisel when the solidity number is being determined. Two types of molds are necessary, the

one (J), 20 by 20 by 90 mm in size, used in the determination of toughness number, and the other (K), 22 by 22 by 90 mm in size, used for making briquettes to be oven dried. These molds may be made of wood as shown in the figure, or of metal. (L) is a wire stirrup in which briquettes are suspended for drying.

Proceeding with the determination of the toughness number, place one of the wet briquettes on the balance platform top side up on the prism (H), and balance with the sliding weight so that the pointer stands at zero on the scale. Determine (once and for all) the force (x) in grams which must be applied at the end of the beam to move such a load from 0 to 10 on the scale. Adjust the briquette on the prism so that the end projects over the end of the prism about 1 cm, then place under the chisel, and lower the chisel until it touches the briquette squarely at a point 1 to 2 mm behind the end of the prism, and so that the pointer stands at zero on the scale. Now hang the light cloth bag on the end of the beam and run into it from the hopper above sufficient sand to cause the pointer to descend to 10 on the scale, that is to cut 10 mm into the wet briquette as Atterberg has specified. If the briquette has been molded properly, the bulk of the sand will be required to cut the first 5 mm, after which the cutting will be rapid. Weigh the sack and contents to grams on a beam balance. Make at least five determinations on each briquette and calculate the average. From this average result subtract the value (x) found above and multiply by the factor 4.37. Repeat using the second briquette and calculate the average.

The pieces of wet briquette cut off each time should be added to the residue of wet soil from which the briquettes were made and which is saved for determination of the solidity number.

THE SOLIDITY NUMBER

The wet soil used above in the determination of the toughness number should be mixed thoroughly, 3 to 5 cc of water being added as appears necessary to make up for evaporation losses, and two briquettes prepared as above, using, however, a 22 by 22 by 90 mm mold. After removal from the mold, each briquette is marked on top near one end by dots and placed in a screen wire stirrup. If the coefficient of linear shrinkage is desired, two fine marks are made with a sharp knife on the upper side of the briquette about 7 cm apart, their exact distance being measured to 0.1 mm with a metric ruler. The briquettes are then suspended in a dessicator over concentrated sulfuric acid and allowed to remain until they appear dry. They are then suspended in an oven and drying is completed at 110°. After cooling

in a dessicator, the distance apart of the knife scratches is measured, and the linear shrinkage calculated in percentage of the original distance between the two marks. The result is a fair approximation of the *coefficient of linear shrinkage* as defined by Tempany (13). The briquettes should be kept in a dessicator until one is ready to determine their solidity numbers. Good results cannot be obtained if the briquettes absorb much hygroscopic moisture.

Continuing with the determination of the solidity number, remove from the balance the prism used in the determination of toughness, and in its place put the block (I) carrying the steel 90° cutting edge, also remove the cloth bag and have at hand the bucket (C). Place the briquette on the platform and balance the load with the sliding weight. Now place the briquette over the knife edge, and adjust the chisel so that it touches the briquette squarely over the knife edge. Hang the bucket on the hook and run in sand from the hopper until the briquette breaks. For heavy soils which require more than a bucket full of sand, some lead or iron weights may be placed in the bucket at the start. If the briquette shows a tendency to tip due to faulty adjustment, a little wedge should be placed under one end. Place the two half briquettes back in the dessicator while the bucket of sand is being weighed. Each half briquette should likewise be broken to obtain an average. Discard any result obtained where the fracture is very irregular. The bucket of sand should be weighed to the nearest 10 grams on a solution balance, and the average weight multiplied by 4.37 to get the force on the balance platform.

The force required to break briquettes varies directly as their width (3, p. 172), hence the average width of each briquette should be determined. Lay the four broken pieces of briquette side by side and top side up on a metric ruler and read their combined width. Invert and read again. Calculate the average width from these readings and reduce the force required to break the briquette to a basis of 20 mm width. The result is the solidity number.

EXPERIMENTAL DATA

THE UPPER PLASTIC LIMIT

Table 1 shows the concordance of duplicate determinations of the upper plastic limit for 16 different soils selected at random from our records. In all cases duplicates agree as closely as is ordinarily expected in the determination of a well-standardized constant like the moisture equivalent.

Table 2 shows the agreement between single determinations of the upper plastic limit made independently by two workers, R and W. The results obtained by W exceed those obtained by R in all cases but

two, however, on the average the difference is only 0.8. In 4 cases out of the 20 the difference exceeds 1.0. Apparently, two individuals may consistently disagree on the end point in this determination by almost 1%.

TABLE 1.—*Concordance of duplicate determinations of the upper plastic limit.*

Sample No.	High	Low	Average	Departure from average
A	37.5	36.7	37.10	0.40
B	43.7	43.1	43.40	0.30
C	47.1	46.2	46.65	0.45
D	35.0	34.6	34.80	0.20
E	35.0	34.9	34.95	0.05
F	39.8	39.4	39.60	0.20
G	34.8	34.6	34.70	0.10
H	33.8	33.0	33.40	0.40
I	34.0	33.6	33.80	0.20
J	27.4	27.0	27.20	0.20
K	25.6	25.0	25.30	0.30
L	40.0	39.0	39.50	0.50
M	36.4	36.0	36.20	0.20
N	30.0	29.8	29.90	0.10
O	31.4	30.8	31.10	0.30
P	31.8	31.0	31.40	0.40
Average	35.2	34.7	34.94	0.27

TABLE 2.—*Agreement between duplicate determinations of the upper plastic limit made by independent observers, R and W.*

Sample No.	R	W	Average	Difference, W—R
2886	28.7	29.1	28.90	0.4
2888	32.5	33.1	32.80	0.6
2890	37.6	38.4	38.00	0.8
2892	29.4	29.8	29.60	0.4
2894	31.5	32.4	31.95	0.9
2896	35.4	36.2	35.80	0.8
2898	38.5	38.0	38.25	—0.5
2900	29.5	30.0	29.75	0.5
2902	28.5	30.5	29.50	2.0
2848	31.4	31.8	31.60	0.4
2850	33.0	32.9	32.95	—0.1
2852	35.8	36.4	36.10	0.6
2701	37.4	39.6	38.50	2.2
2860	41.0	43.2	42.10	2.2
2708	36.4	38.0	37.20	1.6
Average	33.8	34.6	34.20	0.8
Average deviation....................................				±0.9

THE LOWER PLASTIC LIMIT

Table 3 shows the concordance of triplicate determinations of the lower plastic limit on 16 soils, the data being selected at random from our records. Replicated determinations do not seem to check as

closely as in the case of the upper limit of plasticity, however, the agreement is generally satisfactory.

TABLE 3.—*Concordance of triplicate determinations of the lower plastic limit.*

Sample No.	High	Medium	Low	Average	Maximum departure from average
a	31.0	28.7	27.8	29.16	1.84
b	27.6	26.2	26.0	26.60	1.00
c	25.8	25.8	25 2	25.60	0.40
d	26.8	26.0	25.6	26.13	0.67
e	26.9	25.8	24.8	25.83	1.07
f	26.0	25.7	25.6	25.76	0.24
g	29.0	28.6	27.7	28.43	0.73
h	27.2	26.7	25.9	26.60	0.70
i	25.8	25.4	25.2	25.46	0.34
j	25.8	24.4	23.8	24.66	1.14
k	28.0	27.8	26.4	27.40	1.00
l	31.4	30.2	30.0	30.53	0.87
m	35.2	35.0	34.6	34.93	0.33
n	30.0	28.0	27.6	28.53	1.47
o	28.7	28.4	28.2	28.43	0.27
p	29.9	27.6	27.2	28.23	1.67
Average	28.4	27.5	26.9	27.60	0.80

Table 4 shows the agreement of single determinations of the lower plastic limit made by two observers, R and W working independently. The results obtained by W exceed those obtained by R in 50% of the cases. On the average, the difference is zero. Deviations in individual cases are on the same order as those in Table 3.

From the data shown in the four tables above the ideal end point appears to be more definite in the case of the lower than in the case of the upper plastic limit, however, it appears harder to obtain experimentally. It has been our experience that the element of personal fatigue is a factor in getting satisfactory agreement between determinations of the lower limit of plasticity, for some soils at this wetness are extremely hard to mix[4]. In the case of the upper plastic limit two individuals may disagree first in what they consider to be the proper flowage, and second in the violence with which the dish is struck against the hand. It is the opinion of the authors that the former is more important than the latter. Wintermeyer (16) has described a technic for determining the upper plastic limit which should eliminate, if such is possible, both types of error. However, the data which he presents do not indicate any greatly superior advantage of his technic over that used in obtaining the data in Tables 1 and 2.

[4]Recently it has been discovered that very stiff soils may be satisfactorily manipulated by pounding with a hammer. This suggestion has been incorporated in the experimental methods given above. Recent data indicate that replicated determinations on such soils check as consistently as on any others.

TABLE 4.—*Agreement between single determination of the lower plastic limit made by independent observers, R and W.*

Sample No.	R	W	Average	Difference, W—R
3228	22.5	22.6	22.6	0.1
3229	24.8	22.8	23.8	—2.0
3230	21.6	22.8	22.2	1.2
3239	25.6	25.5	25.6	—0.1
3240	23 4	21.4	22.4	—2.0
3241	22.6	21.6	22.1	—1.0
3242	26.3	25.3	25.8	—1.0
3244	23.1	23.7	23.4	0.6
3308	29.4	28.3	28.9	—1.1
3309	26.2	27.5	26.9	1.3
3310	23.9	24.0	24.0	0.1
3311	22.8	24.6	23.7	1.8
3312	23.7	23.5	23.6	—0.2
3313	23.6	23.0	23.3	—0.6
2810	25.6	25.5	25.6	—0.1
2811	25.6	26.8	26.2	1.2
2812	22.9	23.0	22.9	0.1
2813	23.5	22.3	22.9	—1.2
2814	21.2	23.8	22 5	2.6
2815	22.6	23.6	23.1	1.0
2856	30.2	29.5	29.9	—0.7
2858	25.1	26.2	25.7	1.1
2860	24.8	25.6	25.2	0.8
2886	26.8	24.7	25.8	—2.1
2888	25.7	25.3	25.5	—0.4
2890	32.6	31.4	32.0	—1.2
2892	24.6	26.0	25.3	1.4
2894	25.3	24.4	24.9	—0.9
2896	30.6	30.6	30.6	0.0
2898	35.6	35.1	35.4	—0.5
2908	26.0	25.8	25.9	—0.2
2902	25.6	26.6	26.1	1.0
2701	30.3	30.7	30.5	0.4
2708	30.6	30.0	30.3	—0.6
2848	25.6	26.3	26.0	—0.7
2850	26.1	26.7	26.4	0.6
2852	26.1	26.7	26.4	0.6
Average	25.74	25.74	25.75	0.0
Average deviation.				±0.86

THE SCOURING POINT

In Table 5 is shown the concordance of duplicated determinations of the scouring point for 16 soils. The data show about the same variation between duplicates as is found in the determination of the upper and lower limits of plasticity.

The agreement between single determinations of the scouring point made by two independent workers is shown in Table 6. The values

TABLE 5.—*Concordance of duplicate determinations of the scouring point.*

Sample No.	High	Low	Average	Departure from average
3227	31.0	30.5	30.8	0.30
3228	30.7	28.6	29.7	1.10
3229	30.5	28.3	29.4	1.10
3230	31.1	30.6	30.8	0.30
3231	31.6	30.2	30.9	0.70
3309	33.0	32.6	32.8	0.20
3310	31.8	31.7	31.7	0.10
3311	29.4	28.3	28.9	0.60
3312	30.4	30.3	30.3	0.10
3313	30.6	30.2	30.4	0.20
3272	33.5	33.4	33.4	0.10
3273	28.8	28.2	28.5	0.30
3274	30.0	28.0	29.0	1.00
3276	29.3	28.5	28.9	0.40
3246	29.3	29.2	29.2	0.10
3247	28.0	26.3	27.1	0.90
Average	30.6	29.7	30.15	0.47

found by worker W exceed those found by R in 50% of the cases. On the average the two workers agree. In individual cases deviations are larger than in replications by the same worker.

TABLE 6.—*Agreement between single determinations of the scouring point made by independent observers, R and W.*

Sample No.	R	W	Average	Difference, W—R
2856	40.7	41.6	41.15	0.9
2858	33.9	35.4	34.65	1.5
2860	34.2	32.9	33.55	—1.3
2886	31.1	30.4	30.75	—0.7
2888	33.9	33.3	33.60	—0.6
2890	40.4	41.0	40.70	0.6
2892	27.8	30.5	29.15	2.7
2894	32.3	32.4	32.35	—0.1
2896	40.2	42.4	41.30	2.2
2898	42.3	43.0	42.65	0.7
2900	33.3	31.4	32.35	—1.9
2902	33.4	30.5	31.95	—2.9
2701	43.2	42.8	43.00	—0.2
2848	33.4	34.2	33.80	0.8
2850	32.8	32.3	32.55	—0.5
2852	35.0	33.8	34.40	—1.2
2854	34.8	33.5	34.15	—1.3
2708	41.7	43.9	42.80	2.2
Average	35.8	35.9	35.82	0.1
Average deviation				±1.2

In the earlier stages of the studies on the scouring point determination, the authors were repeatedly embarrassed by the data of one workman not checking with that of another, and just as frequently by

finding that one could not always satisfactorily duplicate his own work. However, one never appeared to have trouble in getting determinations replicated the same day to check. It was finally discovered that the difficulty lies in the fact that soils possess two types of scouring points, one, kinetic, and the other, static, precisely as bodies in general possess both kinetic and static coefficients of friction. Hence, the rapidity with which the spatula is drawn over the soil in making the scouring test causes variation in the results.

Apparently, at a certain moisture content a soil will scour without question, no matter what the speed with which the spatula is drawn across it. If the soil is made progressively more moist, it will continue to scour if the spatula is removed more and more slowly, but finally it may be made so wet that the soil clings to the spatula no matter how slowly it is removed. The latter wetness may be called the "static" or "upper" scouring point. It probably has no significance. The practical scouring point would seem to be that at which the speed of removing the spatula simulates the speed of soil over the surface of a shovel or moldboard. Fortunately, such a speed (3 to 5 feet per second) seems to be well beyond the critical requirements, and simply removing the spatula "quickly" seems to give as low a scouring point as can be found. This may be designated the "kinetic" or "lower" scouring point, or simply the scouring point.

Table 7 shows the upper and lower scouring points of 10 selected soils. The soils are arranged in the table according to the magnitude of the difference between their two scouring points. The significance of this difference has not been investigated. Experience indicates that the upper scouring point can be obtained with the same degree of accuracy as the lower.

TABLE 7.—*The upper (static) and lower (kinetic) scouring points of selected soils.*

Soil	Upper scouring point	Lower scouring point	Difference
Houston clay from Texas	69.2	29.5	39.7
Susquehanna clay from Alabama	70.5	33.6	36.9
Paulding clay from Ohio	48.9	32.0	16.9
Carrington clay subsoil (4530) from Nebr.	50.5	34.6	15.9
Carrington clay loam (4515) from Nebr.	50.2	35.6	14.6
Carrington clay loam (4495) from Nebr.	46.1	33.7	12.4
Carrington silt loam (4441) from Nebr.	45.1	33.6	11.5
Carrington silt loam (4463) from Nebr.	41.5	31.5	10.0
Carrington silt loam (4529) from Nebr.	41.2	33.3	7.9
Leonardtown silt loam from Maryland	35.9	30.3	5.6

Sandy soils, have indistinct kinetic scouring points and no static scouring point. They do not stick to the spatula, neither do they polish it, but instead a muddy film of water adheres to it throughout a wide range of moisture content.

THE TOUGHNESS NUMBER

The authors have found it very convenient for two persons to work together in determining the toughness and solidity numbers. The practise has been for one person to make one briquette, and the other its duplicate. The making of neat looking soil briquettes is an art, and it might seem that the personal error involved in molding would be serious. Table 8 shows the agreement in the case of 20 soils between the toughness numbers of briquettes molded by two individuals. Each datum in the second and third columns of the table is the average of five determinations on a single briquette. In the fourth column of the table is shown the mean toughness number of the two briquettes. The fifth column shows their numerical difference, and the last column their difference expressed as percentage of the corresponding mean.

TABLE 8.—*Agreement between toughness number determination on briquettes made by two individuals, R and W.*

Soil No.	R	W	Mean	Difference, W—R	Percentage difference, W—R
3249	144	179	162	35	21.6
3248	175	201	188	26	13.8
3246	249	258	254	9	3.5
3226	310	293	302	—7	—2.3
3227	319	312	315	—7	—2.2
3228	363	341	352	—12	—3.4
3009	380	337	358	—43	—12.0
3276	393	341	367	—52	—14.2
3272	450	433	442	—17	—3.9
3012	555	542	549	—13	—2.4
3231	652	520	586	—132	—22.5
3273	617	739	678	122	18.0
3230	674	704	689	30	4.4
3011	718	735	727	17	2.3
3229	705	854	780	149	19.1
3241	822	809	816	—13	—1.4
3242	875	813	844	—62	—7.3
3274	928	915	922	—13	—1.4
2860	1,125	1,089	1,107	—36	—3.3
2812	1,106	1,228	1,167	—122	—10.3
Average					0.8%
Average deviation					±8.5%

On the average, the values obtained on briquettes molded by W are only 0 8% larger than those obtained by R, which fact seems to indi-

cate that the personal factor in molding the soil is negligible. Duplicate briquettes, however, do not always give closely agreeing results. In 8 cases out of 20 the difference is over 10% of the total, and on the average ±8.5%. If highly accurate toughness numbers are desired, it is obviously necessary to mold more than two briquettes.

THE SOLIDITY NUMBER

In the determination of solidity numbers also, the practise has been for one person to prepare one briquette, and the other person its duplicate, three breaks being obtained on each. Table 9 shows the agreement between toughness numbers thus obtained on 20 soils. On the average, the data obtained on briquettes molded by W exceed those of R by 1.6% which seems to indicate that the personal element in molding is likewise insignificant in this determination. The results on duplicate briquettes disagree widely; in four cases from 10 to 22%, and on the average ±7.2%

TABLE 9.—*Agreement between solidity number determinations on single briquettes made by two individuals, R and W.*

Soil No.	R	W	Mean	Difference, W—R	Percentage difference, W—R
3246	27.2	21.9	24.6	—5.3	—21.5
3249	30.6	24.5	27.6	—6.1	—22.1
3276	37.3	34.9	36.1	—2.4	—6.6
3239	38.4	36.6	37.5	—1.8	—4.8
3226	44.1	42.3	43.2	—1.8	—4.2
3247	48.8	47.4	48.1	—1.4	—2.9
3248	48.1	49.8	49.0	1.7	3.5
3009	49.3	49.2	49.3	—0.1	—0.2
2810	57.7	50.4	54.1	—7.3	—13.5
3272	56.5	62.6	59.6	6.1	10.2
3227	61.2	60.6	60.9	—0.6	—1.0
2816	64.9	60.4	62.7	—4.5	—7.2
3230	58.1	67.2	62.7	9.1	14.5
3010	64.6	63.2	63.9	—1.4	—2.2
3228	63.7	69.6	66.7	5.9	8.7
3274	64.2	70.3	67.3	6.1	9.1
2811	68.3	67.2	67.8	—1.1	—1.6
3012	65.2	70.9	68.1	5.7	8.4
3011	72.3	72.0	72.2	—0.3	—0.4
3241	84.5	86.2	85.4	1.7	2.0
Average					1.6%
Average deviation					±7.2%

THE EFFECT OF SOIL DESSICATION

In order to obtain the uniformly mixed soil sample that is necessary if consistent replications are to be obtained, it is ordinarily desirable that samples be dried and ground. This raises a question as to the

effect of the drying process on the results. In order to determine this effect, 10 soil samples were brought from the field in the moist condition, and after being passed through a 2-mm sieve, and mixed thoroughly, were each divided into three portions. One portion was preserved in the field moist condition in a sealed container. The second was air dried for several months and then ground to pass a 0.5-mm sieve. The third was oven dried for 48 hours at 110° and likewise ground. None of the soils contained coarse particles that would be crushed in the grinding process. Finally, the upper and lower plastic limits and the scouring point of each portion were determined in quadruplicate. The data are shown in Table 10. Samples 4441 to 4529, inclusive, are cultivated surface soils of the Carrington series. Sample 4530 is the subsoil of 4529. Samples 2974 to 2977, inclusive, are the 0 to 6 and 7 to 12 inch and second and third foot sections, respectively, of virgin Marshall silt loam.

On the average, air drying increased the upper and lower plastic limits slightly but had no effect on the plasticity number or on the scouring point. In individual cases, air drying increased the plastic limits more often and more significantly than it decreased them. Oven drying decreased the magnitude of the Atterberg constants consistently and significantly, however, not so much as might be anticipated considering the known effects of such extreme dessication on colloidal properties in general. No study has been made of the effect of dessication on the toughness and solidity numbers.

Obviously, soils should not be oven dried for determination of the Atterberg constants. Fortunately, the effects of air drying are not serious. Why air drying increased while oven drying decreased the plastic limits is not clear. Perhaps air drying has no effect at all, the real effect being the result of the mechanical condition of the product.

SUMMARY

This paper deals with the estimation of soil consistency by means of methods proposed originally by Atterberg and designated herein as the Atterberg consistency constants. The several constants with which the paper is concerned are the upper and lower plastic limits, the plasticity number, the scouring point, and the toughness and solidity numbers. The procedure for the determination of each constant is discussed and a new form of apparatus for cutting and breaking soil briquettes is described.

The upper and lower plastic limits and the scouring point, which are evaluated in terms of moisture content, are shown to be determinable to a degree that compares favorably with determinations of the

TABLE 10.—*The effect of air and oven drying on the Atterberg consistency constants of field moist soils.*

Soil No.	Field moist	Air dry	Oven dry	Departure from field moist: Air dry	Departure from field moist: Oven dry
		Upper Plastic Limit			
4441	29.5	29.3	26.0	—0.2	—3.5
4463	27.4	27.6	24.5	0.2	—2.9
4495	33.5	35.0	30.7	1.5	—2.8
4515	32.7	32.2	29.0	—0.5	—3.7
4529	31.2	32.0	28.7	0.8	—2.5
4530	37.4	39.0	38.0	1.6	0.6
2974	38.5	39.2	34.7	0.7	—3.8
2975	40.1	40.0	35.4	—0.1	—4.7
2976	40.7	42.8	37.7	2.1	—3.0
2977	39.5	39.5	35.7	0.0	—3.8
Average	35.1	35.7	32.0	0.6	—3.1
		Lower Plastic Limit			
4441	24.7	24.8	21.7	0.1	—3.0
4463	22.8	24.4	21.9	1.6	—0.9
4495	22.8	23.8	22.0	1.0	—0.8
4515	24.8	26.0	23.1	1.2	—1.7
4529	23.2	23.9	22.5	0.7	—0.7
4530	22.9	21.7	21.5	—1.2	—1.4
2974	30.3	31.0	27.8	0.7	—2.5
2975	28.3	28.1	25.9	—0.2	—2.4
2976	25.6	27.3	25.0	1.7	—0.6
2977	22.8	23.3	22.7	0.5	—0.1
Average	24.8	25.4	23.4	0.6	—1.4
		Plasticity Number			
4441	4.8	4.5	4.3	—0.3	—0.5
4463	4.6	3.2	2.6	—1.4	—2.0
4495	10.7	11.2	8.7	0.5	—2.0
4515	7.9	6.2	5.9	—1.7	—2.0
4529	8.0	8.1	6.2	0.1	—1.8
4530	14.5	17.3	16.5	2.8	2.0
2974	8.2	8.2	6.9	0.0	—1.3
2975	11.8	11.9	9.5	0.1	—2.3
2976	15.1	15.5	12.7	0.4	—2.4
2977	16.7	16.2	13.0	—0.5	—3.7
Average	10.2	10.2	8.6	0.0	—1.6
		Scouring Point			
4441	33.7	33.6	30.6	—0.1	—3.1
4463	31.5	31.5	29.5	0.0	—2.0
4495	34.8	33.7	32.7	—1.1	—2.1
4515	35.4	35.6	32.7	0.2	—2.7
4529	34.2	33.3	31.1	—0.9	—3.1
4530	36.1	34.6	34.6	—1.5	—1.5
2974	44.7	44.6	40.5	—0.1	—4.2
2975	36.6	37.8	35.6	1.2	—1.0
2976	36.1	37.2	34.3	1.1	—1.8
2977	33.4	34.3	31.9	0.9	—1.5
Average	35.6	35.6	33.3	0.0	—2.3

moisture equivalent. The personal factor in estimating end points seems to be of minor concern.

The determinations of the toughness and solidity numbers are not highly reliable unless well replicated. The personal factors in molding soil briquettes are of small consequence on the average. However, results on paired briquettes may vary as much as 20%.

Air drying and grinding of samples preliminary to determination of the upper and lower plastic limits and the scouring point generally raises the values slightly over the same soils in field moist condition. Oven drying almost invariably reduces the values several per cent. It is concluded that samples may be safely air dried and ground, but should not be oven dried.

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THE ROOTS OF FLAX PLANTS[1]

A. C. Arny and I. J. Johnson[2]

Flax is grown annually on from two and a half to three millions of acres of land in the United States. During the war and the years immediately following, this acreage was somewhat less. The crop is grown mainly in the Dakotas, Minnesota, and Montana and in the parts of Canada to the north of these states. A knowledge of the rooting habits of flax under the varying soil and rainfall conditions where it is grown is of importance in planning cropping sequences and cultural practises.

From the standpoint of a general study of root systems, information regarding the flax crop may be used to supplement that on other crops given in the recent publication on "Root Development of Field Crops" by Weaver.

PREVIOUS WORK ON THE ROOT SYSTEM OF FLAX

As early as 1890, Ten Eyck (6)[3] made available a photograph of flax roots washed from the soil and the following description, "The flax has a different sort of a system of rooting from that of any other of the plants studied. A single, small thread-like tap-root runs vertically downward, giving off many small rather short side roots and feeders in the first 12 to 18 inches. Some of the roots reach a depth of 3 feet. The roots of flax do not form a net-work of roots near the surface as do those of wheat and oats, nor do they occupy the soil so completely. From the fact that flax is noted for decreasing fertility of the soil, I expected to find a much larger and stronger root development."

This was followed by additional work by the same author (7) giving another photograph of the roots of a flax plant grown in 6-inch drill rows, washed from the soil at maturity, and descriptive matter as follows, "Flax has a different system of rooting from that of wheat or oats. Its roots do not go so deep (2½ to 3 feet in this sample), but it makes a much greater fibrous root growth in the upper 2 feet of the soil. Each plant sends down a single, small tap-root, which gives off many small side roots or branches, and these in turn give off numerous fibrous roots or feeders. The upper branches soon curve downward

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[3]Reference by number is to "Literature Cited," p. 380.

along with the main root which grows rapidly, slender and thread-like, until it can scarcely be distinguished from its branches. By its intricate system of rooting, flax occupies the soil very completely. The crop is not so deep a feeder as wheat or oats, but it is doubtless a much closer feeder, and withdrawing the water largely from the upper part of the soil, it is apt to leave the ground in a dry, unfavorable mechanical condition at the close of the season, which sometimes, perhaps, works injury to succeeding crops. To its close feeding habit, also we may attribute the subduing effect which flax has on new land. When a crop of flax gets a good hold on ground, it tends to starve out other plants."

Shepperd (5) followed in 1905 with additional studies which confirmed in the main the results of previous work. The following statement summarized the results with the roots of flax washed from the soil at maturity, "The roots of this specimen of flax had reached a depth of 4 feet and, like flax plants examined during previous seasons, they grew almost directly downward and branched very little."

Rotmistrov (3, 4) gives the depth and spread of flax roots in inches at different stages of development of the plant as follows: 7 days, 6.7 by 0.8; 14 days, 9.8 by 2.3; 21 days, 15 7 by 6.3; beginning flowering, 30 by 19.7; beginning of maturity, 42.3 by 25.2. No illustrations are given, but the statement is made that while grasses have three main roots, dicotyledonous plants have but one. He conveys the idea that flax like potatoes does not use up all the reserve water in the soil and hence spring grain may follow flax in rotation to advantage as far as moisture supply is concerned He says, "The root system of flax penetrates to a less depth than grass cereals and leaves a certain water reserve."

Modestov (2) ascertained that flax plants growing under field conditions had the following root penetration at the three stages of development given: (a) 10- to 12-leaf stage vertical root a trifle over 8 inches in depth; (b) plants nearing the completion of above-ground growth, main root 20.5 inches deep with only a few of the main roots deeper than 8 inches; (c) growth above ground completed, main roots 25 inches deep; (d) maturity, roots 27 to 34 inches. The roots continued to grow after extension of the plants above ground had ceased.

Howard (1) illustrates the depth and spread of the roots of two types of flax plants that are grown in flax-producing areas having widely different conditions so far as soil moisture and soil type are concerned, as follows:

1. The peninsular type grown mostly in central India where soil moisture is usually the limiting factor. Plants of this type are rapid

growers with few branches and comparatively deep roots with few or no branches near the surface. This type of plant is best adapted to the growing season cut short by drouth where large cracks occur in the surface soil and moisture must be secured from lower depths. These varieties have seeds of large size.

2. The alluvium type. Slow growing, medium to late maturing varieties with the possibility of producing many branches, root system shallow with many branches near the surface. Adapted to conditions where moisture near the surface is rarely a limiting factor. Production of flowers and seeds after the first bolls are mature accompanied by extension of the root system is characteristic of a few of the varieties having deeper tap roots than average.

OBJECTS OF THE WORK

The main objects of the work with the root systems of flax at University Farm, St. Paul, Minn., at the present time are (a) to learn the effect of variations in soil and moisture on the kind and extent of the root system of the same or different varieties, and (b) to correlate differences in root development with yield. The work was well started in 1927 and will be continued.

METHODS OF WORK

A trench 2 feet wide and approximately 2 feet deeper than the roots of the plants were apt to extend was dug about 4 inches from the plants to be examined. An ice pick, a tool having a gently tapering very sharply pointed steel piece approximately the size of a lead pencil at the base and the length of an unused lead pencil inserted into a straight wooden handle about 5 inches long, was used almost exclusively in tracing the roots. The soil was first removed from the root near the top and the main roots and branches in the plane represented by the surface of the trench were traced, measured, and sketched on large sheets of a good grade of brown wrapping paper laid off in convenient squares. After the operator became accustomed to the work, there was no difficulty in getting accurate drawings of the roots as they occurred in the undisturbed soil. The roots of a number of plants were traced in each case and such changes made in the drawings as were necessary to make it representative.

After the trenches were dug, it took the following number of hours by an experienced worker to trace the roots and make the rough drawings of the main and branch roots for the figures given: Fig. 1, 2 hours; Fig. 2, 4 hours; Fig. 3, 6 hours; Figs. 4 and 5, 8 to 10 hours.

Roots were examined in the two soil types. The soil at University Farm is classified as Hempstead silt loam which totals only approximately 1,000 square acres in the state. The surface soil is a black silt

loam underlaid with light-colored material of a fine texture for from 2 to 3 feet followed by fine sand and then sand and gravel. Average yields over a period of years on this type of soil are very similar to the yields on other types of mineral soil in the same section of the state.

Roots were traced at Crookston which is located in the Red River Valley. The soil here is residual with the surface of a black clay to clay loam and the subsoil a clay. The surface is flat and drainage is slow. This is the same type of soil that occurs at Fargo where Ten Eyck and Shepperd did their work on the roots of flax and other crops.

The rainfall at each of the two locations is given in Table No. 1.

TABLE 1.—*Rainfall and departure from normal at St. Paul and Crookston, Minn.*

Month	St. Paul Rainfall in inches	St. Paul Departure from normal in inches	Crookston Rainfall in inches	Crookston Departure from normal in inches
April	2.16	−0.17	2.09	+0.27
May	2.59	−1.03	4.40	+1.57
June	3.98	−0.43	4.83	+1.33
July	2.11	−1.29	2.35	−0.99
August	1.95	−1.51	3.71	+1.01

At University Farm the rainfall was somewhat less than normal which would tend to bring about more branching and greater depth of root penetration. The yields of seed of several varieties ranged from 18 to 24 bushels per acre. These yields indicate that the supply of moisture in the soil was ample. There was an excess of rainfall in May and June at Crookston. The amount of moisture in the soil was somewhat above optimum. At University Farm the flax was planted April 29 and on subsequent dates. At Crookston the planting was delayed due to the presence of too much water in the soil beyond the usual date. The planting was done May 19.

RESULTS OF STUDIES IN 1928

Studies of the root development of plants of the Winona variety were made at a number of different stages of development at University Farm, a few of which are shown in the accompanying figures. The roots of a number of varieties were studied at full bloom and at maturity.

RESULTS AT UNIVERSITY FARM

Roots were traced at a number of stages in the early development of the plant. A root from a flax plant 22 days from seeding is shown in Fig. 1. The main root was traced to a depth of 21 inches, and the lateral spread of the numerous main branches near the surface 10.5 inches. At this time the plants were 7 inches tall. The depth of penetration of the main root of the flax plant at this age compares

favorably with that of the roots of other plants that are generally considered rapid growers.

The type of root shown in Fig. 1 resembles in general that of the mature plant of the alluvium type shown and described by Howard (1).

An average root traced 44 days from date of planting is given in Fig. 2. The plants were 24 inches tall and were beginning to bloom. The main root penetrated to a depth of 37 inches

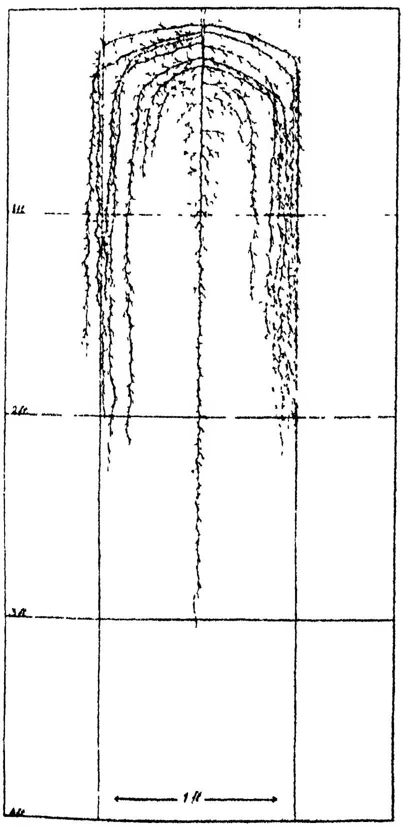

FIG. 2.—Root of Winona flax 44 days from seeding.

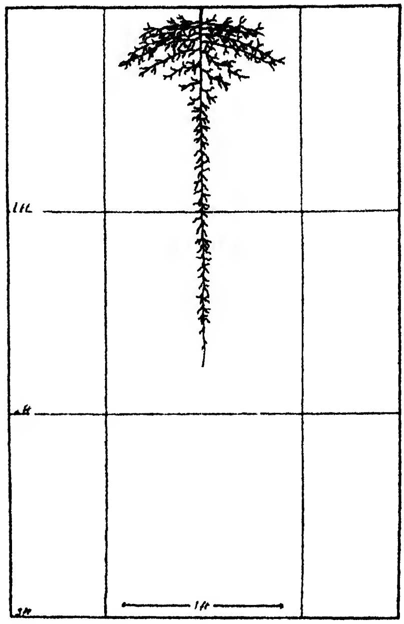

FIG. 1.—Root of Winona flax 22 days from seeding.

and the spread was slightly over 1 foot. The main branch roots turned down sharply and several of them reached a depth of slightly over 2 feet.

At the time of full bloom and a few days past that stage the root development had extended as shown in Fig. 3. During the two weeks that intervened between the stage shown in Figs. 2 and 3, the development consisted mainly of extension in length of both the main and the branch roots.

The roots were traced again at the time the bolls were well formed and when a few were turning brown and at maturity.

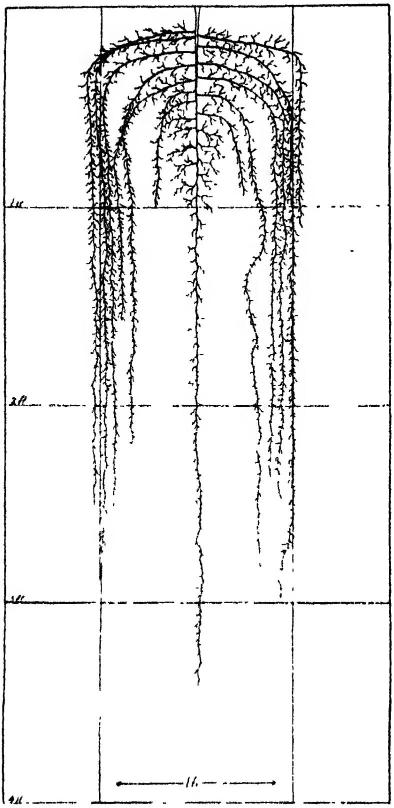

FIG. 3.—Root of Winona flax 58 days from seeding.

At maturity, 94 days from the time of seeding, the average root extended as shown in Fig. 4. The main root had reached a depth of nearly 4 feet. The main branches coming off from the upper portion of the main root, which were well on their way down at the 44-day period, had grown downward more rapidly than the main root and consequently several of them were nearly as long as the main root and similar to it in diameter and number of smaller branch roots and rootlets. The main root had increased 2 to 3 inches and the branch roots approximately 10 inches during the interval of three weeks between the time the bolls were well formed with a few beginning to turn brown and mature. The sketch of the flax roots given by Ten Eyck (7) is similar to this in general outline Where the plants stood at the usual thickness in the row but with the rows 18 inches apart instead of 6 inches, the main branch roots had a 6- to 8-inch greater spread before turning downward.

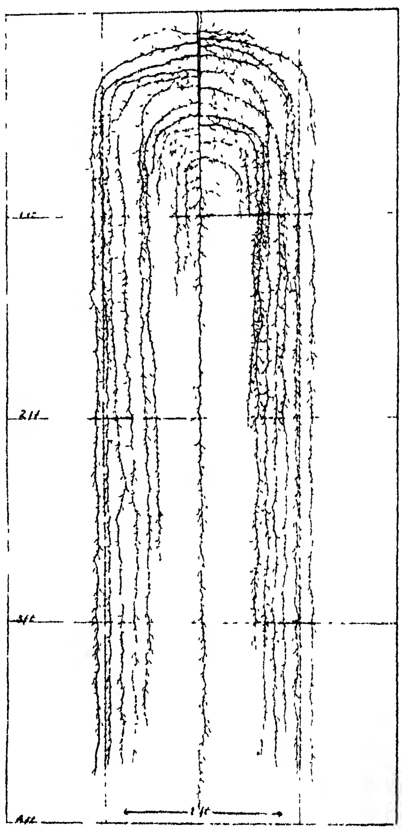

Fig. 4.—Root of Winona flax at maturity, 94 days from seeding.

The roots of plants of the large-seeded types, which Howard (1) showed and described as having deep roots with few or no branches near the surface of the soil, were traced and the same general type of development of roots was found as for plants of the small-seeded type shown in Figs. 1 to 4, inclusive.

Roots of plants of flax with small brown seeds secured from the Howard collection were traced at maturity. The same general type of root development as is seen in Fig. 4 was found, but the branch roots are markedly larger in diameter. This indicates a varietal difference in root character but in a variety outside of those in general use in the flax-growing section of the United States. Further work may bring out differences between the rooting habits of varieties now used, particularly on some soils and under different moisture conditions.

RESULTS AT CROOKSTON

Roots of plants of both the small- and large-seeded types were traced at maturity on August 28 and 29. An average root of the small-seeded type of plant is shown in Fig. 5. The only differences between roots of the two types appeared to be a somewhat lower number of main branches on the roots of the large-seeded type and that these branches grew somewhat straighter out from the main root then they did on the roots of the small-seeded type.

The roots of the mature plants at Crookston lacked the development of the main branch roots shown in the plants at University Farm at all stages after that shown in Fig. 1. This is brought out by comparing the roots shown in Figs. 4 and 5 both of which were traced at maturity. The root shown in Fig. 5 is similar to that shown in Fig. 1 in general

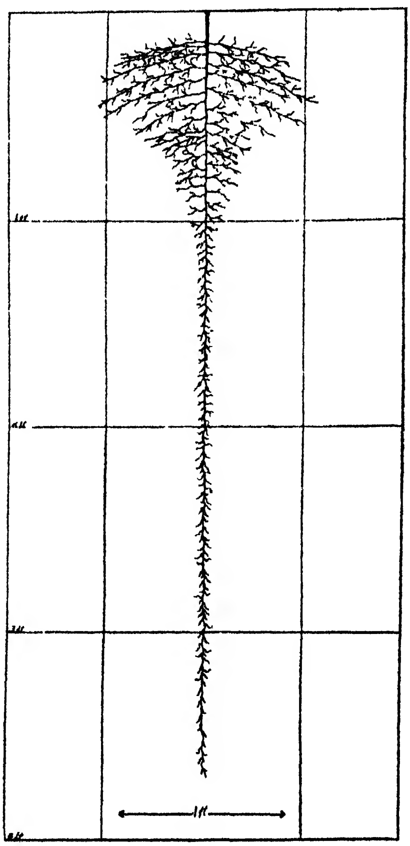

FIG. 5.—Root of Winona flax at maturity, Crookston.

outline. Under conditions at Crookston the main roots developed about as they did at University Farm, but the main branch roots did not develop in the vertical direction to any extent, at least not even the ends, so far as they could be traced, had turned downward sharply.

It appears that the main cause of the difference in the root development of the same varieties at University Farm and Crookston in 1926 was the water supply as modified by the type of soil in which the plants grew.

During May and June there was at Crookston an excess of about 3 inches of rain. The soil at Crookston drains very slowly and hence the excess in May and June tended to balance off the slight deficiency in July so that the moisture supply was above optimum during the entire growing season. Under these conditions the plants secured the water they needed without an extensive root system.

The yields of seed at University Farm were 18.4 bushels per acre for the small-seeded type Winona and 23.5 bushels for the larger seeded type. At Crookston these yields were 11.0 and 9 2 bushels per acre, respectively, which is little more than half the yields secured at University Farm. Average yields over a period of years at University Farm and Crookston have been approximately equal for the small-seeded varieties. The large-seeded varieties come near equalling the small-seeded varieties at Crookston, but usually fall considerably short of doing so at University Farm.

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EFFECT OF LIME ON THE AVAILABILITY OF PHOSPHORUS IN SUPERPHOSPHATE (ACID PHOSPHATE)[1]

HENRY C. HARRIS[2]

It has been customary to assume that when lime and superphosphate (acid phosphate) are mixed the phosphorus reverts. The following equation can be written for the reaction:

$$CaH_4(PO_4)_2 + CaCO_3 = Ca_2H_2(PO_4)_2 + H_2O + CO_2$$

$$Ca_2H_2(PO_4)_2 + CaCO_3 = Ca_3(PO_4)_2 + H_2O + CO_2$$

This equation attempts to explain the change in a chemical way. Agriculturally, however, people are interested in learning whether such mixing will influence the yield of crops. The farmer is not greatly concerned in the reversion of superphosphate (acid phosphate) provided he gets the proper response from his fertilizer. It has been the purpose of the writer to ascertain whether mixing lime with superphosphate (acid phosphate) decreases the value of the phosphate from the standpoint of its effect on the plant and also to re-study by chemical analysis the question of reversion.

REVIEW OF LITERATURE

Brackett and Freeman (2)[3] mixed ground limestone and superphosphate (acid phosphate) in varying proportions up to 50% of lime and found that the water soluble phosphorus reverted. Their conclusions are as follows:

"I. Tri-calcium phosphate is produced on mixing acid phosphate and ground limestone.

"II. The formation of the tri-calcium phosphate begins immediately on mixing, but increases slightly on standing, showing that the amount formed is a function of both time and temperature.

"III. Considering the closeness with which manufacturers guarantee today, it appears necessary that the formation of insoluble (phosphorus) in such mixtures be taken account of in making guarantees."

Working with somewhat larger quantities of materials than did Brackett and Freeman, Magruder (8, 9) found essentially the same things. Instead of mixing ordinary ground limestone with superphosphate (acid phosphate), he used ground oyster shells.

More chemical work along this line was done by James (6, 7). Both CaO and $CaCO_3$ (the $CaCO_3$ in the form of coral sand) were mixed with superphosphate (acid phosphate). In both cases reversion took

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[3]Reference by number is to "Literature Cited," p. 393.

place. The larger quantities of lime caused more reversion, and the rate was rapid at first and slowed up with time.

Perhaps as good a piece of chemical work as has been done on the subject of the reversion of superphosphate (acid phosphate) was done by Hall and Vogel (5). Two limestones with different physical and chemical properties were used. The ungraded limestone and the various grades of limestone were mixed with the superphosphate (acid phosphate), and analyses made at intervals of from 1 hour to 12 weeks. In each case 2,000 grams of superphosphate (acid phosphate) were mixed with 900 grams of the limestone. The fine grades of limestone reverted the water soluble phosphorus rather quickly, and a rather larger percentage of it was reverted, while the coarser material reverted a smaller quantity of the phosphorus and the change took place more slowly. Usually most of the change had taken place in two weeks.

Another extensive piece of chemical work along this line was done by Fraps (3) at the Texas Experiment Station. Both precipitated $CaCO_3$ and commercial hydrated lime were mixed with superphosphate (acid phosphate), and analyses made at various intervals of time. Reversion took place in both cases, but the effect was more vigorous with the hydrated lime. In the case of $CaCO_3$ the reaction was not complete in 20 days.

At the same time Fraps carried on pot experiments to see if there would be any bad effect on the crop from mixing the two. Corn and sorghum were grown. While the crops are said to have not grown very well and while the results are not conclusive, there does seem to be an indication that the value of superphosphate (acid phosphate), so far as the crop is concerned, is decreased by mixing lime with it.

A review of the literature leads to the conclusion that superpohsphate (acid phosphate) reverts when lime is mixed with it, but there is little evidence to indicate what effect mixing will have on the availability of the phosphorus to plants. The latter point is the object of this investigation.

TYPES OF EXPERIMENTS

Originally, the plan was to conduct only vegetative tests in the greenhouse. After this work was begun, however, Neubauer and Schneider (10) reported a method of ascertaining the nutrient needs of the soil by means of seedlings, and it was decided to carry out some experiments of this kind. It was also planned to make a few chemical analyses to see if the superphosphate (acid phosphate) used in the pot experiments actually did revert when mixed with ground limestone.

Thus, the work is divided under three heads, *viz.*, (a) pot experiments in the greenhouse, (b) Neubauer-Schneider experiments, and (c) chemical analyses of mixtures of superphosphate (acid phosphate) and lime. These groups will be discussed in the order named.

PLAN OF GREENHOUSE EXPERIMENTS

The plan of the pot experiments was to grow a number of different plants on soils that would respond to phosphorus. Ontario loam and Volusia silt loam were selected. In some cases the pots were to be treated with lime, in others with lime and superphosphate (acid phosphate) put on at different times, and in still others with lime and superphosphate (acid phosphate) which were mixed two weeks previous to their application. The details of these experiments follow.

POT EXPERIMENTS IN THE GREENHOUSE

The pot experiments were conducted as follows: Three-gallon, glazed earthenware pots were used, and 12,000 grams of air-dry soil were placed in each pot. In one or two experiments a little more soil was used and in one or two a little less, but usually 12,000 grams were most convenient Moisture determinations of the soil were made so that it would be possible to calculate the amount of water to apply to the growing crops. In filling any set of pots care was taken to mix the whole bulk of soil well so that the soil of the pots would be as uniform as possible. Stones larger than a walnut were thrown out. In each greenhouse experiment performed 12 pots were used.

The plan was to treat the first four pots with lime, the second four pots with lime and superphosphate (acid phosphate), the lime to be put in the soil two weeks before the superphosphate (acid phosphate), and the third four pots with lime and superphosphate (acid phosphate) which had been mixed well and allowed to stand two weeks before putting in the soil. Exposure to air at laboratory temperature was the only drying given the lime and superphosphate (acid phosphate). This procedure was followed all through the experiments. Thus, lime was applied to the first eight pots of an experiment on one day, and on the same day lime and superphosphate (acid phosphate) were weighed out and mixed to be applied to the last four pots two weeks hence. After the lime had been put on the first 8 pots, all 12 of the pots were moistened so that any reaction would take place freely. At the end of the two weeks, superphopshate (acid phosphate) alone was put on the second 4 pots, and the superphosphate (acid phosphate)-lime mixture on the third 4 pots. In every case the lime and superphosphate (acid phosphate) were well mixed with the soil.

A basic treatment of 1.08 grams of $NaNO_3$ and 0.6 gram of KCl was applied to each pot. This is equivalent to 180 pounds of $NaNO_3$ and 100 pounds of KCl per acre. These two fertilizers in solution were put on the pots at the end of the two weeks period when the lime-superphosphate (acid phosphate) mixture was applied. The KCl-$NaNO_3$ solution was prepared so a 50-cc pipette would draw out the required quantity. These 50 cc were diluted to 1 quart with distilled water and about half of this mixture was applied to the soil near the bottom of the pot, while the other half was applied near the top.

The amount of superphosphate (acid phosphate) and lime used varied to some extent and will be given in each experiment.

Limestone containing 97% $CaCO_3$ and 2% $MgCO_3$ which would pass through a 100-mesh sieve, finely ground, high grade superphopshate (acid phosphate), and commercial $NaNO_3$ and KCl were used.

In germinating the seed the soil was sprinkled lightly, usually each morning, till the plants were up. Soon after they appeared 20% of water calculated on the dry soil basis was used till the plants became well established, after that 25%. During the early growth of the plants it was not necessary to put the pots up to weight very often, but after the plants became well established the pots were put up to weight twice a week, and occasionally during periods of clear hot weather it was necessary to do this three times a week. In all these experiments distilled water was used for watering the plants. The position of the pots on the benches in the greenhouse was changed so varying degrees of light and temperature would not be a factor.

Barley (variety Alpha) and wheat (variety Galgalos) grew to maturity, except in experiment 1 when the plants were harvested somewhat after the stage of full bloom. Fifteen plants were grown in each pot. Corn (variety Smut Nose) was grown as fodder, there being seven corn plants per pot. Both crops passed the blooming stage. Twenty sweet clover plants were left in each pot after thinning out. The soil was inoculated with the proper *radicicola* organism. The plants reached a stage suitable for hay.

Results from all the greenhouse tests have been condensed into two tables—those conducted on Ontario loam being recorded in Table 1 and those on Volusia silt loam in Table 2. Figures given are for the entire crop, except in the case of ripe barley and wheat for which the yields of grain alone are used.

DISCUSSION OF POT EXPERIMENTS

In all of the experiments recorded in Tables 1 and 2 there was a significant response in crop yield to applications of superphosphate (acid phosphate). Both soils were, therefore, such as could properly be used in an experiment of this kind.

An examination of the yields resulting from mixing the limestone and superphosphate (acid phosphate) before application as compared with applying separately shows that in only two cases has there been any significant decrease in yield from the practise of mixing. Both of the experiments with sweet clover show diminished yield where the mixture was used. On the whole it may be said that mixing the lime and superphosphate (acid phosphate) two weeks before applying to the soil has not caused plants to make less growth than when the two are applied separately at an interval of two weeks, except in the case of sweet clover. Whether this may be interpreted to mean that some kinds of plants suffer from this treatment while others do not is perhaps an unqualified assumption. The exception stands out rather prominently, however, and such an interpretation might be used as an hypothesis in further work. If such legumes as sweet clover, alfalfa, and red clover are affected adversely by mixing lime and superphosphate (acid phosphate) before applying, it is an important consideration since lime is likely to be used for these crops. On the other hand, it is well worth knowing that the cereals are not injured in this way on either the acid or neutral soil used in this experiment.

HOW A NEUBAUER TEST IS PERFORMED

Within the last few years, Neubauer and Schneider (10) in Germany have developed a new method of determining the nutrient needs of the soil by means of seedlings, and the method has been well received in that country. The essentials of the method are as follows: 100 grams of carefully prepared soil is placed in the bottom of a glass dish having a diameter of 11 cm and a depth of 7 cm. With this soil is mixed 50 grams of pure sand. The greater part of 250 grams of sand, which has been sterilized, is spread over this sand-soil mixture. The remainder of the sand is saved to cover the seeds, thus the seeds are planted between layers of the pure sand. Rye seeds are used, and 100 kernels are carefully selected for each dish. Neubauer thinks they should weigh at least 40 grams to the thousand. "Upsulun," a chlorophenol-mercury compound, is used to sterilize the seeds before planting. A glass tube for watering is placed in the center of each dish, and after planting, the water content of the soil-sand mixture is

TABLE 1.—*Yields of crops grown on Ontario loam.*

No.	Treatment method	Yields, dry weight in grams, average of four pots: Experiment 1, Barley	Experiment 2, Sweet clover	Experiment 3, Corn	Experiment 4, Wheat
1	Lime, no superphosphate (acid phosphate)	10.23±.36[a]	2.73±.18	55.56±2.66	8.65±.21
2	Lime and superphosphate (acid phosphate) applied separately	11.68±.29	3.98±.12	70.03±0.70	10.85±.45
3	Lime and superphosphate (acid phosphate) mixed	13.88±.44	3.33±.10	70.35±0.70	12.00±.26
	In favor of treatment No. 2 over No. 1	1.45±.46[b]	1.25±.22	14.47±2.75	2.20±.50
	In favor of treatment No. 3 over No. 2	2.20±.53	0.65±.16[c]	0.32±0.99	1.15±.52

[a]In all these experiments the probable error of the mean was calculcated by Bessel's formula.

[b]The formula, probable error of the difference $=\sqrt{E_1^2+E_2^2}$ was used in all cases in calculating the error of the difference. E_1 and E_2 represent the probable error of the means.

[c]In this case in favor of No. 2 over No. 3.

TABLE 2.—*Yields of crops grown on Volusia silt loam.*

No.	Treatment method	Yields, dry weight in grams, average of four pots: Experiment 5, Barley	Experiment 6, Sweet Clover	Experiment 7, Corn	Experiment 8, Wheat
1	Lime, no superphosphate (acid phosphate)	15.95±.27	25.47±.22	53.00± .86	11.91±.21
2	Lime and superphosphate (acid phosphate) applied separately	21.70±.36	28.07±.17	58.45± .85	15.11±.21
3	Lime and superphosphate (acid phosphate) mixed	20.46±.45	26.95±.23	55.57±1.65	14.59±.16
	In favor of treatment No. 2 over No. 1	5.74±.45	2.60±.28	5.45±1.21	3.20±.30
	In favor of treatment No. 2 over No. 3	1.24±.58	1.12±.29	2.88±1.82	0.52±.30

brought up to 80 grams. The plants are grown for a period of from 14 to 18 days, and then the entire plants, seedlings and their rootlets, are removed and analyzed for phosphorus and potassium.

DETAILS OF EXPERIMENTS

It is not the purpose of the writer to defend this method. It has been widely accepted in Germany as a means of telling the amount of available phosphorus in the soil. If it will do this, it seems that one could treat a soil with superphosphate (acid phosphate) mixed with lime and the same soil with superphosphate (acid phosphate) applied at a different time to the lime, and ascertain in which case the phosphorus was more available. That is the idea back of these experiments. They were performed in triplicate and the plan was as follows: The first three dishes were to be treated with lime, the second three with lime and superphosphate (acid phosphate) put on at different times, and the third three with superphosphate (acid phosphate) that had been mixed with lime.

Both the Neubauer experiments were conducted as follows: Precautions were taken to get uniform samples of soil, and the soil was passed through a 10-mesh sieve so that no stones would be in it. Moisture determinations were made, and sufficient soil weighed out in each dish to make 100 grams of dry soil. The first and second three dishes of soil were treated with lime, the lime being mixed thoroughly with the soil Twenty per cent of water calculated on the dry soil basis was added to all dishes at this time, whether treated with lime or not, so that any reaction might take place readily and all dishes would be uniform. Then the dishes were covered with pieces of glass to prevent evaporation. On the same day that lime was applied to the first and second three dishes, samples of superphosphate (acid phosphate) and lime were weighed out and mixed, and after these mixtures had stood for two weeks they were applied to the third set of dishes. At the same time this mixture was applied to the third set of dishes, superphosphate (acid phosphate) alone was put on the second set of dishes. In order that nitrogen and potash would not be deficient, a basic treatment of $NaNO_3$ and KCl in solution was applied to all the dishes at the time the superphosphate (acid phosphate)-lime mixture was applied to the last three. Then, the sand was mixed with the soil, and everything was in readiness for planting. The rye seeds were sterilized by soaking for three hours in a 2% chlorine solution formed from bleaching powder. After the rye had been planted, the water content of the dishes was brought up to 80 grams, and after the plants came up the dishes were brought up to weight each day.

The fertilizer materials used were superphosphate (acid phosphate) ground fine, limestone fine enough to pass through a 100-mesh sieve, and "chemically pure" $NaNO_3$ and KCl.

ANALYSIS OF PLANTS

The analysis of the plants was made in the following way: The entire crop from each dish—tops, old seeds, and rootlets—was placed in a platinum dish. The contents were moistened with water, and 2 cc of saturated solution of $Mg(NO_3)_2$ were added. The dish was then placed in a muffle furnace on a heavy asbestos board, and the temperature raised to the lowest capacity of the furnace until the contents of the dish were dry and started to burn. Finally, the temperature was raised to a dull red, and the vent muffled to permit a slow passage of air over the dishes. Burning was continued till the contents of the dishes were entirely white. The materials were then cooled, moistened with water, and 5 cc of concentrated HCl added to each. The platinum dishes were covered with watch glasses, and the contents digested over a water bath for two hours. The dissolved material was made up to 250 cc in a volumetric flask and allowed to settle. Fifty-cc aliquots of these solutions were analyzed by a modification of the volumetric method of Scott (11). Instead of filtering out the ammonium phosphomolybdate by means of a Gooch crucible containing asbestos as is used in the Scott method, an ordinary filter paper was employed. The beaker in which the precipitation was done was washed with 1% HNO_3, and then washed free of the acid with 1% KNO_3. The filter paper, on which most of the ammonium phosphomolybdate collected, was then washed with 1% HNO_3, and this acid removed by washing with neutral 1% KNO_3. The filter paper, precipitate and all, was returned to the beaker in which originally the precipitation had been done. Then the precipitate was dissolved with standard NaOH, and 50 cc of boiling distilled water added to hasten solution. The excess NaOH was titrated back with standard HNO_3.

TABLE 3.—*Plan of fertilizer treatment in experiment 9.*

Dish No.	Grams basic treatment per dish	Grams superpohsphate (acid phosphate) per dish	Grams lime per dish
1	0.01 KCl		
2	and	None	0.1
3	0.018 $NaNO_3$		
4	0.01 KCl		
5	and	0.02	0.1
6	0.018 $NaNO_3$		
7	0.01 KCl	0.02	0.1
8	and	mixed with lime	mixed with superphosphate
9	0.018 $NaNO_3$		(acid phosphate)

NEUBAUER DETERMINATIONS ON ONTARIO LOAM

The dishes for the ninth experiment were prepared in the way described above. On June 22, 1926, the rye was planted, and it was up June 27. The rye grew very well and was harvested July 11. The treatment is given in Table 3.

While being harvested, two of the dishes were broken. The results of the analysis of the other seven dishes are given in Table 4.

TABLE 4.—*Weights of rye seed planted and the analyses of the seedlings grown in experiment 9.*

Dish No.	Weight of seed in grams	Total phosphorus in crop in grams expressed as P, average of two closely checking determinations	Check in grams calculated for 1 gram seed
1	4.1262	0.016729	0.004054
2	4.1722	0.015409	0.003666
3	4.2844	0.016104	0.003758
		Average check for 1 gram seed	=0.003826 ±0.0000789
5	4.1822	0.016217	Average increase over check = 0.001001 gram P ±0.0005288
Check for 4.1822 grams seed		=0.016001	
		Increase 0.000216	
6	4.1998	0.017853	
Check for 4.1998 grams seed		=0.016068	
		Increase 0.001785	
8	4.1992	0.017751	Average increase over check = 0.001821 gram P ±0.0000917
Check for 4.1992 grams seed		=0.016066	
		Increase 0.001685	
9	4.0680	0.017520	
Check for 4.0680 grams seed		=0.015564	
		Increase 0.001956	

This experiment indicates that the dishes to which superphosphate (acid phosphate) was applied contained larger quantities of phosphorus in the plants than those not receiving superphosphate (acid phosphate). Where the lime was mixed with superphosphate (acid phosphate), the analyses gave as much phosphorus and even more.

The phosphorus added to this soil in the form of superphosphate (acid phosphate) would amount to less than 2 miligrams, and the author was not certain that such small amounts could be detected by this method. For this reason it was decided to repeat the experiment on the same soil, using larger quantities of superphosphate (acid phosphate).

Everything was prepared in the way already described. March 15, 1927, the rye was planted, and the plants were up by March 21. The

rye grew well, and was harvested on April 6. Table 5 gives the treatment.

TABLE 5.—*Plan of fertilizer treatment in experiment 10.*

Dish No.	Grams basic treatment per dish	Grams superphosphate (acid phosphate) per dish	Grams lime per dish
1	0.01 KCl		
2	and	None	0.1
3	0.018 $NaNO_3$		
4	0.01 KCl		
5	and	0.06	0.1
6	0.018 $NaNO_3$		
7	0.01 KCl	0.06	0.1
8	and	mixed with lime	mixed with superphosphate
9	0.018 $NaNO_3$		(acid phosphate)

It will be noted that three times as much phosphate was used in this experiment as in the previous one. The results of the analyses of this repeated experiment are given in Table 6.

DISCUSSION OF NEUBAUER EXPERIMENTS

These two experiments were performed in different years on the same soil, and it is noticeable how closely the checks agree in the two experiments. The analyses of the plants for phosphorus gave higher values in the second experiment than in the first, and the extra quantity seems to be somewhat proportional to the extra amount added in superphosphate (acid phosphate). Mixing the phosphate and lime does not affect the availability of phosphorus to rye, if the Neubauer method is a reliable guide. In fact, the dishes in which lime and superphosphate (acid phosphate) were mixed gave slightly more phosphorus. In several of the pot experiments on Ontario loam the best results were secured when superphosphate (acid phosphate) and lime were mixed, and thus the two types of experiments agree very well.

CHEMICAL ANALYSES OF FERTILIZERS

In order to be certain that this particular lot of superphosphate (acid phosphate) used would revert when mixed with lime, it was decided to determine the water soluble phosphorus of the fertilizer istelf, and, also, to determine the water soluble phosphorus of the fertilizer after lime had been mixed with it and the mixture allowed to stand for several days.

On April 1, 1927, four 2.4-gram samples of superphosphate (acid phosphate) were weighed out. To each of two of these was added 12 grams of lime, and the materials were thoroughly mixed. The superphosphate (acid phosphate) was ground fine and the lime would pass through a 100-mesh sieve. The samples were allowed to stand until

TABLE 6.—*Weights of rye seed planted and the analyses of the seedlings grown in experiment 10.*

Dish No.	Weight of seed in grams	Total phosphorus in crop in grams expressed as P, average of two closely checking determinations	Check in grams calculated for 1 gram seed
1	4.0920	0.016587	0.004053
2	4.2250	0.016322	0.003863
3	4.3618	0.014919	0.003420
		Average check for 1 gram seed	=0.003779 ±0.0001268
4	4.1738	0.017820	
Check for 4.1738 grams seed		=0.015773	
		Increase 0.002047	
5	4.1134	0.018549	Average increase over check = 0.002912 gram P ±.0003197
Check for 4.1134 grams seed		=0.015544	
		Increase 0.003005	
6	4.0468	0.018975	
Check for 4.0468 grams seed		=0.015292	
		Increase 0.003683	
7	4.3370	0.019667	
Check for 4.3370 grams seed		=0.016389	
		Increase 0.003278	
8	4.1492	0.019908	Average increase over check = 0.003507 gram P ±.0002488
Check for 4.1492 grams seed		=0.015679	
		Increase 0.004229	
9	4.2230	0.018972	
Check for 4.2230 grams seed		=0.015958	
		Increase 0.003014	

April 17, when the water-soluble phosphorus was determined. The method of the Association of Official Agricultural Chemists was used. The solutions were diluted to 500 cc and convenient aliquots were analyzed by the modified Scott method mentioned under the Neubauer method. The results are given in Table 7.

TABLE 7.—*Amount of lime mixed with superphosphate (acid phosphate) and the results of analyses for water soluble phosphorus.*

No. of sample of superphosphate (acid phosphate)	Grams lime mixed with superphosphate (acid phosphate)	Phosphorus as P_2O_5 expressed in percentage, average of two closely checking determinations
1	12	1.6395
2	12	2.2115
3	None	16.8504
4	None	17.7062

These results indicate that most of the phosphorus reverts within 17 days when lime is mixed with superphosphate (acid phosphate).

But the lime and superphosphate (acid phosphate) were air dry, and the idea occurred to the writer that reversion might take place in the process of analysis. To test this each of two samples of 2.4 grams of superphosphate (acid phosphate) were weighed out, mixed with 12 grams of lime, and analyzed for water soluble phosphorus immediately. The results are given in Table 8.

TABLE 8.—*Water soluble phosphorus in superphosphate (acid phosphate) analyzed immediately after lime was mixed with it.*

No. of sample of superphosphate (acid phosphate)	Phosphorus as P_2O_5 expressed in percentage, average of two closely checking determinations
1	5.2655
2	6.3898

While mixing superphosphate (acid phosphate) with lime and allowing the two to stand does seem to cause the phosphorus to revert to some extent, this experiment indicates that most of the reversion takes place in the analytical process itself.

GENERAL CONCLUSIONS

The pot experiments performed on both Ontario loam and Volusia silt loam are believed to show that mixing superphosphate (acid phosphate) and lime does not decrease the value of the fertilizer for many plants. White sweet clover may be an exception and, if so, belongs to a group of plants having a different ability to utilize the phosphorus of the lime-superphosphate (acid phosphate) mixture.

The Neubauer experiments performed on Ontario loam show the same thing as the pot experiments in which cereals were used. Chemical analyses of superphosphate (acid phosphate) mixed with lime and not mixed with lime show reversion of the $CaH_4(PO_4)_2$, but apparently most of it takes place in the analytical process itself. In view of this, one would not expect the mixing of air-dry lime with superphosphate (acid phosphate) to have as pronounced an effect as has been supposed.

Taking all these points into consideration, the writer believes that, in general, mixing lime with superphosphate (acid phosphate) is not open to as much objection as has usually been ascribed to it.

SUMMARY

1. A review of the literature is given.

2. Pot experiments, in which a number of different plants were used, were made on both Ontario loam and Volusia silt loam.

3. The results of the pot experiments on Ontario loam were substantiated by the Neubauer method.

4. Chemical analyses were made of superphosphate (acid phosphate), both mixed and not mixed with lime. Reversion occurred, but most of it seemed to take place in the analytical process.

5. The general conclusion is that mixing lime and superphosphate (acid phosphate) before applying them to the soil is not detrimental to the yields of most kinds of plants but may be to some.

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BULBOUS BLUEGRASS, *POA BULBOSA*[1]

H. N. VINALL AND H. L. WESTOVER[2]

Bulbous bluegrass, *Poa bulbosa*, which forms true bulbs at the base and bulblets in the inflorescence, is reported as indigenous in southern Europe and Asia and in northern Africa. It is now widely distributed over nearly all of the temperate and subtropical regions of the world, and has been reported from England, Germany, France, Italy, Russia, Algeria, Afghanistan, India, South Africa, and South Australia. Its introduction into the United States may have been effected through the importation of alfalfa or clover seed. The bulblets of *Poa bulbosa* are not uncommon in alfalfa seed from Turkestan and have been found in alfalfa seed from France and in red clover seed from Italy. Drying the bulblets does not kill them. They will germinate after lying around in a dry atmosphere for a year or more. They behave like seed when stored in a dry place and can be handled in the same way. There is nothing, therefore, to have prevented their introduction into the United States in importations of clover and alfalfa seed.

Bulblets of this grass were received by the Office of Foreign Plant Introduction, U. S. Department of Agriculture, from the Samara Government of Russia in December, 1906. These were grown by the Office of Forage Crops in the Arlington Experimental Farm grass garden in 1907, 1908, and 1909, and at Pullman, Wash., in 1907, but the grass was reported as having no particular promise and no further distribution of it was attempted.

It was not until 1915 that this grass was again brought to the attention of the Department of Agriculture. In that year it was found growing in the Capitol grounds at Richmond, Va., and sent in for identification. The sender desired advice as to methods for its eradication, considering it undesirable for lawn purposes on account of its failure to grow during the summer. The bulbs which he sent were planted in the greenhouse and identified in 1916 as *Poa bulbosa*. The Richmond people were then advised to cease their efforts to eradicate it, and instead to use it as a winter lawn in combination with Bermuda grass for the summer months. The grass was found also at Ashland, Va., Middletown, Conn., and Bingen and Walla Walla, Wash. No definite information as to how it became established at these points is available, but the presence of the bulblets in

[1]Contribution from the Office of Forage Crops, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication Jan. 20, 1928.

[2]Agronomists.

European alfalfa and clover seed is no doubt sufficient explanation of its presence.

After the identification of the grass from Richmond, Va., in 1916, more bulbs were obtained from that point and small quantities were distributed to several experiment stations and other cooperators of the Office of Forage Crops. It has now become established in many states, but appears to be most at home in the Rogue River Valley of Oregon, where it is spreading naturally in the foothills and produces an abundance of "seed" (bulblets). Medford, Oreg., is the center of the "seed" producing area and the bulblets are now being placed on the market in commercial quantities.

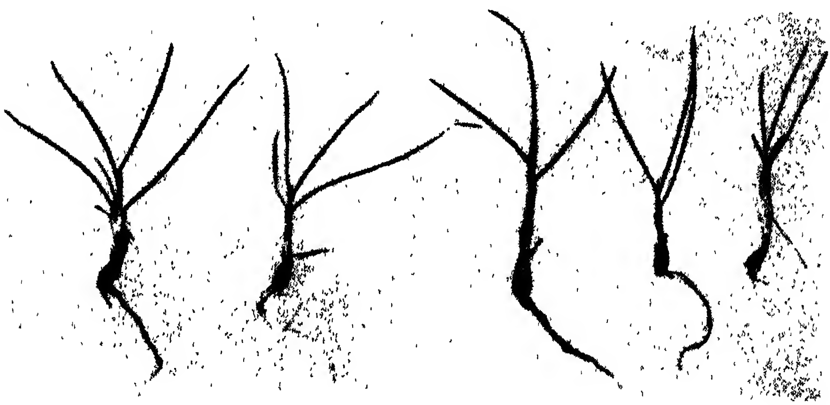

FIG. 1.—Individual plants of *Poa bulbosa* about six weeks old showing the bulbs at the base.

DESCRIPTION

The underground stem of *Poa bulbosa* is a true bulb which when fresh is about the size of a plump wheat grain, and when dry is even smaller. At Washington, D. C., these bulbs lie dormant from about May 15 to October 1. At the latter date on the advent of cool weather fine leaves arise from the top of these bulbs and soon the ground is covered with a green turf. The leaves are much like those of Kentucky bluegrass, but somewhat narrower and of a lighter green. (See Fig. 1.)

During the winter months the growth is slow, and by March 1 it is often only 3 inches tall. As the weather becomes warmer it grows more, but at Washington it produces very few culms. These culms reach a height of 12 to 18 inches and bear at the top a panicle having the appearance of an inflorescence, but in place of seeds producing

tiny bulblets like wild garlic (*Allium canadense*). These bulblets develop about May 1 and soon thereafter the grass begins to yellow and die.

At Corvallis, Oreg., the grass behaves in very much the same way as at Washington, D. C., except that it produces many more culms. It grows splendidly during the fall, winter, and spring, but with the

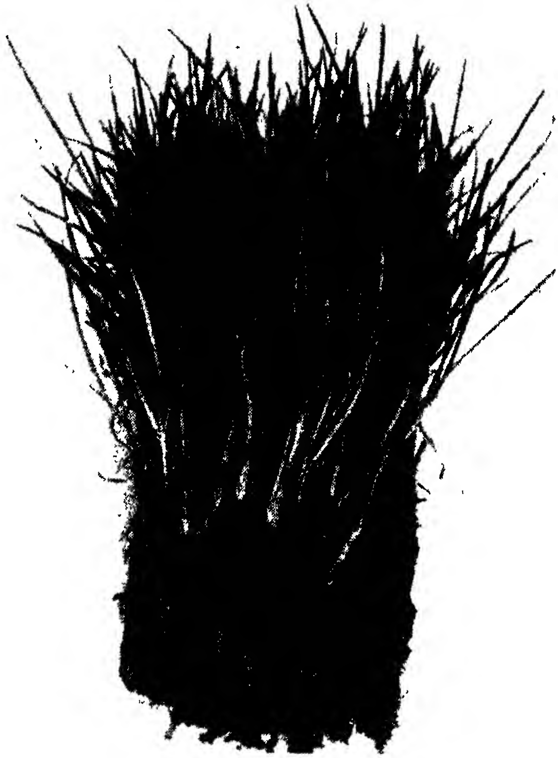

FIG. 2.—A clump of *Poa bulbosa* plants, natural size, showing the manner in which the original plant increases in size by the production of new bulbs at the base.

advent of dry weather growth ceases and in summer the plants are dormant. Growth begins again promptly with the fall rains and the stand thickens each year through the production of new bulbs around the original center. (See Fig. 2.) These clusters spread in one year at Corvallis from a diameter of 2 inches to 8 inches. Producing bulbs both above and below ground, the grass is well fitted to reproduce and spread so that under favorable conditions a thin stand is soon converted into a thick mat of grass.

USES AND VALUE

On account of its habit of growing only during the winter months and remaining dormant throughout the summer, *Poa bulbosa* would seem to be admirably fitted to associate with Bermuda grass on pastures, lawns, and golf courses in the southeastern states. It has not been tested sufficiently to determine its range of usefulness in this respect, but it has persisted in a plat of Bermuda grass at Washington, D. C., since 1917 and made a splendid green turf each winter after the Bermuda was killed by frost. (See Fig. 3.) There is usually an interval of about two weeks between the time the *Poa bulbosa*

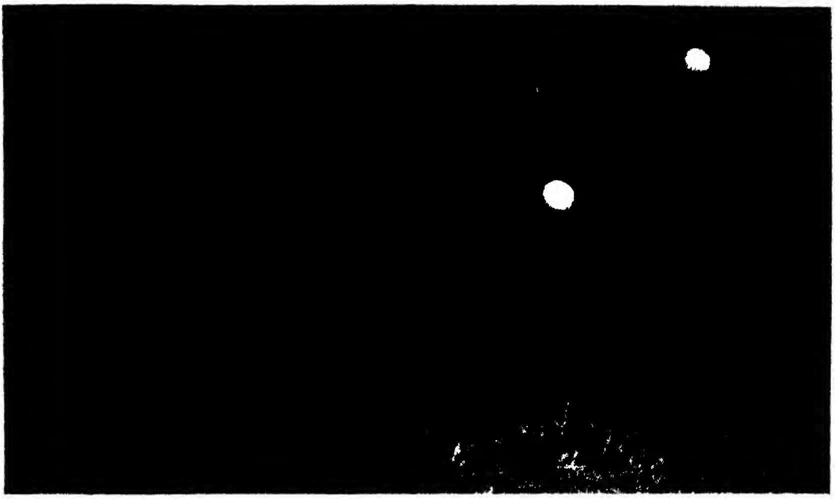

FIG. 3.—A plat of *Poa bulbosa* on Bermuda grass sod at Arlington Farm near Washington, D. C., March 10, 1926. Note the winter condition of the old Bermuda grass turf in the foreground as compared with that of the bulbous bluegrass.

stops growth in the spring and the greening up of the Bermuda grass. In the fall it begins growth about the time that Bermuda grass fails on account of the first frost. There is, therefore, a period of only two weeks when green grass is not available. With Bermuda grass alone the turf is unsightly and unproductive from October 1 to May 15 in the latitude of Washington, and for a slightly shorter period farther south. The practise of sowing Italian or perennial rye grass on Bermuda grass turf in the fall to provide green sward during the winter has been more or less common in the Gulf States. This method requires reseeding each year. *Poa bulbosa*, being a perennial, remains in the sod and renews its growth each year, thus making unnecessary continued reseeding. Since it is dormant during the summer months,

it should not interfere largely with a normal growth of the Bermuda grass and the latter growing only in the summer should not injure the *Poa bulbosa*. At Washington, the Bermuda grass appears to be the member of the association which is injured most, the stand becoming thinner each year. This may be due to the fact that Washington is near the northern limit of Bermuda grass. Farther south the Bermuda grass has a longer growing season and is more aggressive.

This new grass appears to be fairly well adapted for use on the fairways of golf courses where the turf is made up of Bermuda grass. *Poa bulbosa* produces a dense turf which provides a good lie for the golf ball during the winter months when otherwise the ground would be bare. (See Fig. 3.) The opinion has been expressed that this grass will not endure frequent clipping and is, therefore, not adapted for use on putting greens. In the trials on the Arlington turf plats near Washington, D. C., close clipping after the grass had made considerable growth resulted in a stubbly turf not suited to accurate putting, and it recovered slowly after such treatment. Additional investigations may develop methods of clipping that will give better results.

The use of *Poa bulbosa* in pastures has not been tested sufficiently to warrant a recommendation for its general use. In southern Oregon around Medford, Talent, and Ashland where it is most abundant, it is said to add a great deal to the value of pastures during the winter and spring. Both the Oregon and California Experiment Stations report that it is well liked by livestock. Some claim that it thrives only on the better soils where, with irrigation, alfalfa may be grown. It often grows in mixture with alfalfa and rye grass, and then much of the pasturage consists of these two plants. Unless it will thrive on the hill lands where the soil is less productive and drier, it will not prove of much value to the stock raisers. A considerable acreage in Oregon was seeded to bulbous blue-grass last fall. This will provide an opportunity to determine its value on these hill lands.

Whether it can be successfully introduced into the Bermuda grass pastures of the southeastern states, remains to be demonstrated. It has made an excellent growth at the Tennessee Experiment Station at Knoxville, and as the "seed" becomes cheaper and more abundant, extensive pasture tests may be practical in Tennessee and North Carolina. Any predictions at this time as to its real value in southern pastures would be unwarranted.

"SEED" PRODUCTION AND SEEDING

Under favorable conditions, such as exist in southern Oregon, *Poa bulbosa* makes high yields of the bulblets. One grower reports having

harvested 700 to 1,000 pounds per acre on an 80-acre field. The bulbs produced underground are somewhat larger than the bulblets produced in the inflorescence, and much better stands and more rapid growth were obtained at the Arlington Experimental Farm when the bulbs were used in place of the bulblets which are the *Poa bulbosa* "seed" of commercial seed dealers. However, no great difficulty should be encountered in getting a stand if fresh bulblets are planted in the proper manner.

Poa bulbosa should be planted in the fall just before or about the time that the summer grasses cease active growth. This will vary with the latitude from September 1 to October 15. For lawns the usual rate of planting is 3 to 4 pounds of the bulblets per 1,000 square feet. In seeding pastures such a rate would be impractical owing to the cost of the "seed." Thin stands could be obtained with 30 to 40 pounds per acre, and once established the plants would spread by the production of new bulbs as shown in Fig. 2, and gradually thicken the stand.

If the planting is to be made on old Bermuda grass sod, the Bermuda grass should be cut close and the surface scarified or loosened with a rake or harrow before seeding. The bulbs or bulblets are then sown broadcast on this loosened soil and covered with a roller. On lawns when watering is possible, sprinkling after the seeding is completed will hasten the germination of the bulbs or bulblets. On the fairways of golf courses or on pasture lands the grass will not start until a rain occurs unless the soil is moist. Lying in a dry soil for several weeks will not injure the bulbs, however. Seedings made on land not already in grass should follow a careful preparation of the soil as in the case of other grasses. A finely prepared seedbed insures a better germination and consequently results in a saving of rather expensive "seed." The bulbs should not be covered deeply as they naturally grow near the surface of the soil.

THE CHECKER-BOARD METHOD OF LAYING OUT PLATS[1]

J. P. JONES[2]

The checker-board method, as the name implies, consists of an arrangement of plats in a checker-board fashion. The plats are divided into two groups, as shown in Fig. 1, treated plats and checks. With the exception of those treated plats on the border, there are four check plats adjacent to each treated plat. This method has been found especially desirable for a crop such as onions, where, because of thick planting, large numbers of plants occur on small areas, making it possible to use small plats—1/80 to 1/160 of an acre. In the fertilizer experiments with onions at the Massachusetts Experiment Station certain advantages in the use of the checker-board method have suggested themselves which may be of general interest to agronomists.

AIDS IN ATTAINING OBJECTIVE

The checker-board method of laying out plats provides opportunity for change as data warrant, and thus assists in attaining the objective of the experiment. In many fertilizer experiments it is often a question when to change and how to change without sacrifice. Perhaps if some of the long-time experiments had included this principle of change it would not have been necessary to conduct them over such a long period. The checker-board method is based upon the principle of changing. In the beginning the best-known treatment is applied on the check plats. As soon as a better one is recognized among the variously treated plats it is used as the check. If there is doubt about the value of a particular treatment, it may be tested on some of the check plats. This will afford more cases in which it can be observed and will allow its merits to be more definitely judged.

When the experiment has progressed to the stage where the best treatment is on the check plats, and the resources of the project leader in bettering growth on the treated plats are exhausted, then the objective has been attained and the work can be concluded.

GIVES RELIABLE RESULTS

With four check plats adjacent to each treated one, the performance of the latter can be compared with that on four adjacent areas. The consistency with which the checks are better or poorer gives a reliable basis for judging the value of the treatments for any particular portion of the field. If the treatments are replicated several times in different

[1]Contribution from the Department of Agronomy, Massachusetts Agricultural College, Amherst, Mass. Received for publication Jan. 21, 1928.

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parts of the field their merits relative to the checks can be observed for different soil conditions. The data obtained can be treated either by Student's or Bessel's method for estimating their reliability. But frequently the consistency of the relation between the treatments and checks makes the use of statistical methods unnecessary.

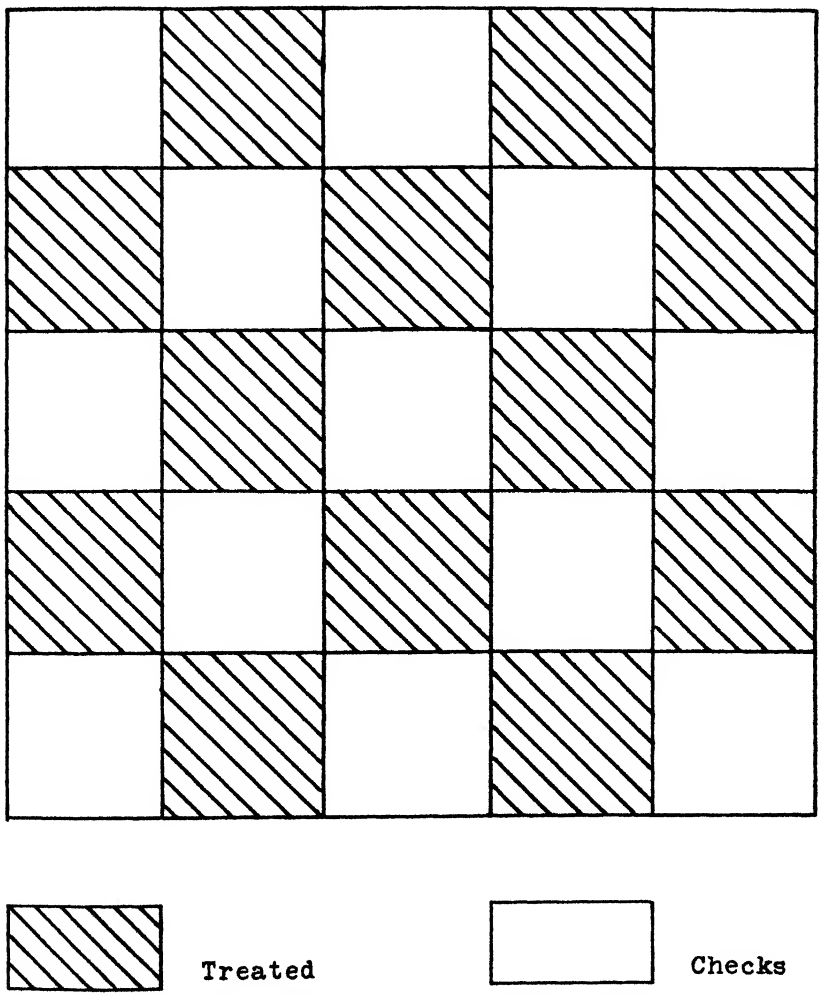

FIG. 1.—Checker-board method of laying out plats.

The use of four checks for each treatment may seem an extravagant use of land. In reality a single check plat may be used for comparison with as many as four different treatments. Thus greater reliability in results may be obtained with no greater number of plats than would be required for the satisfactory use of the Student pairing method.

MAKES UNIFORMITY TESTS UNNECESSARY

In beginning experimental work on a given area it has frequently been the practise to grow a single crop, uniformly treated, for two or three years before beginning the differential treatments. This crop is harvested by plats and the yield records obtained constitute a basis for estimating the soil variations. A previous knowledge of the soil variations makes it possible to avoid them or to use them to advantage when developing the experimental plans. Sometimes it is impossible to do either.

With the checker-board method no such uniformity test is necessary. It is taken for granted that the soil is variable and that the best that can be done is to lay out the plats on as uniform and satisfcatory appearing an area as possible. Plat replications are employed to reduce the errors due to soil variations.

The purposes of the uniformity tests are served by the large number of check plats from which the soil variability can be estimated with sufficient precision for most purposes. The checker-board system thus provides a method whereby the uniformity test can be conducted coincidently with the experiment. This affords a direct approach to the solution of the problems for which any particular fund may have been set aside, and avoids the expenditures of time and money associated with the uniformity test.

MECHANICAL DISPERSION AS AN AID IN THE CHEMICAL STUDY OF SOILS[1]

L. D. BAVER[2]

INTRODUCTION

The rate of reaction in many chemical processes in soils is in part dependent upon the rate at which the chemical reagent comes in contact with the soil particles. This is one reason for using a soil sample ground to pass a 100-mesh screen in the usual chemical analysis. However, in some chemical studies it is not desirable to grind the soil so fine as to crush the mineral particles, but rather to use soil that has been crushed to pass a 20-mesh or 2-mm screen. This is especially true with soil acidity, lime requirement, and base exchange determinations in which grinding has been found to change the results obtained.

The time that is necessary for obtaining equilibrium in soil acidity, lime requirement, and base exchange reactions is influenced by the state of aggregation of the soil particles, since it is necessary for the solution to penetrate these soil masses before complete reaction can be obtained. In a clay soil the aggregates are more tenaciously held together than in a soil of coarser texture, and consequently, a longer time will generally be required for attaining equilibrium. If it were possible to break down these soil aggregates into their individual particles, a more rapid contact between the soil and the solution would result, thereby increasing the rate of reaction and shortening the time necessary for establishing equilibrium.

In this paper there is reported a study of the effect of mechanical dispersion on the establishment of equilibrium in the Jones (3)[3] and Hopkins (2) lime requirement methods and in the determination of exchangeable calcium in soils.

EXPERIMENTAL

The dispersing apparatus used in this investigation is similar to that reported by Bouyoucos (1) except that the metal cup is replaced by a 250-cc beaker. This arrangement is shown in Fig. 1. A 250-cc beaker, A, is fitted with a rubber stopper, B, into which several glass rods, C, are inserted to break up the currents generated by the rapid rotation of the stirrer, D. Bouyoucos (1) has reported that 10 minutes stirring is sufficient for the dispersion of most soils.

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication Jan. 21, 1928.

[2]Assistant in Agronomy (Soils).

[3]Reference by number is to "Literature Cited," p. 410.

DETERMINATION OF THE LIME REQUIREMENT OF SOILS

The Jones (3) lime requirement method is based on the determination of the acid liberated by the addition of calcium acetate to a definite quantity of soil. The titratable acidity thus produced is multiplied by the factor 1.8 to compensate for the acidity not released by a single treatment of the soil with the salt solution.

In the standard method for making this determination the soil is usually ground with the calcium acetate in a mortar, transferred to a 250-cc volumetric flask and made up to volume with distilled water. After standing for about 15 minutes with frequent shaking, the soil

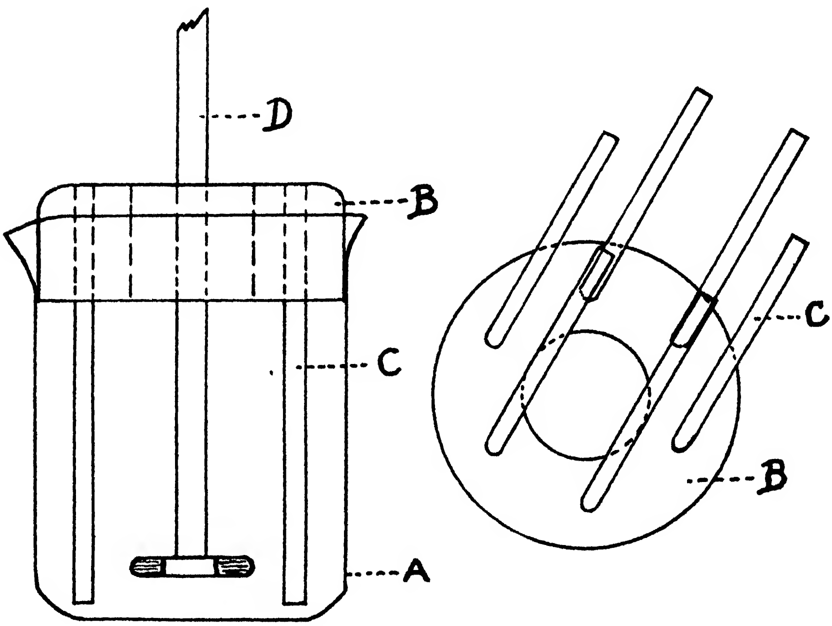

FIG. 1.

suspension is filtered and an aliquot titrated with N/10 NaOH, using brom-thymol blue as the indicator.

The Hopkins (2) method depends on the measurement of the acid liberated upon the addition of a normal potassium nitrate solution to the soil. The titratable acidity is multiplied by the factor 1.25 to compensate for the acidity not released by a single treatment of the sample with the salt solution. In the standard method the soil is shaken with a normal potassium nitrate solution for several hours and allowed to stand over night. A portion of the supernatant liquid is titrated with N/10 NaOH, using phenolphthalein as the indicator.

The procedure for carrying out the Jones method with the aid of mechanical dispersion is as follows: 10 grams of soil are dispersed for

10 minutes in 80 cc of water and 20 cc of a solution of calcium acetate containing 1 gram of acetate to 20 cc of solution. The soil suspension thus obtained is filtered on a Buchner funnel with suction into a clean filter flask and washed with a solution made up of 40 cc of water and 10 cc of the calcium acetate solution. Washing the dispersed soil with the salt solution results in the release of the total acidity capable of being produced by the reaction of the salt solution on the soil, thereby eliminating the use of the factor employed in the ordinary method. The entire filtrate is boiled to expel the CO_2, cooled, and titrated as in the usual method.

The procedure in the Hopkins method is similar, except that the soil is dispersed in a solution containing 60 cc of water and 40 cc of normal potassium nitrate. After filtering, the soil is washed with 80 cc of the normal nitrate solution.

With both methods each cc of N/10 NaOH required to neutralize the acid produced from 10 grams of soil corresponds to a lime requirement of 1,000 pounds of $CaCO_3$ per acre (2,000,000 pounds of soil).

A comparison of the results of the Jones and Hopkins lime requirement determinations as carried out by the regular and the dispersion methods is given in Table 1. These data show that all the acidity produced by the addition of the salt solution to the soil is removed by 10 minutes dispersion and a subsequent washing of the soil with the salt solution. The lime requirement values obtained by the dispersion method without the use of the usual factor agree very well with those of the regular method in which the factor is used. Since this factor is based on the summation of a number of titrations resulting from repeated treatments of the soil with the salt solution used, it would be expected to vary somewhat with different soils.

DETERMINATIONS OF EXCHANGEABLE CALCIUM IN SOILS

In most base exchange studies the soil is leached with some normal salt solution, such as NH_4Cl, NaCl, and CH_3COONH_4. The length of time required for the complete replacement of the exchange cations in the soil by these solutions depends upon the type of soil. A coarse-textured soil will leach much more rapidly than a heavy soil. Extraction by leaching is extremely slow with clay soils, even with the aid of suction. The dispersion method makes possible the replacement of exchange cations in a much shorter time. Dispersion of the soil with a salt solution, followed by washing the filtered soil with an additional quantity of the solution, will give practically complete replacement of the exchangeable calcium. The time required for carrying out this process varies from 15 to 30 minutes, depending upon the type of soil.

TABLE 1.—*Effect of mechanical dispersion upon the lime requirement (pounds of $CaCO_3$ per acre) of soils as determined by the Jones and Hopkins methods.*

Soil	pH	Jones Method: Regular method factor 1.8	Jones Method: Dispersion method, First treatment	Jones Method: Dispersion method, Second treatment	Hopkins Method: Regular method factor 1.25	Hopkins Method: Dispersion method, First treatment	Hopkins Method: Dispersion method, Second treatment
Canfield silt loam (surface)	5.8	3,246	3,030	0	187	350	0
Mahoning silty clay loam (surface)	4.7	4,232	4,290	0	3,312	3,560	0
Clermont silt loam (heavy layer, 24–30 inches)	4.6	12,086	10,300	0	10,605	11,210	50

TABLE 2.—*A comparison of the dispersion and leaching methods for determining exchangeable calcium in soils.*

Soil		pH	Dispersion method %	Dispersion method *mgm. equiv.*	Leaching method[a] %	Leaching method[a] *mgm. equiv.*
Wooster silt loam (surface)	limed	7.65	0.1352	6.76	0.1376	6.88
			0.1364	6.82		
Wooster silt loam (surface)	unlimed	4.85	0 0272	1.36	0.0290	1.45
			0.0272	1.36		
			0.0240	1.20		
Brookston clay (surface)		7.35	0.4944	24.72	0.4667	23.34
			0.4928	24.64		

[a]Determinations by C. J. Schollenberger and F. R. Dreibelbis.

The procedure for determining exchangeable calcium in soils with the aid of mechanical dispersion is as follows: 25 grams of soil passing through a 20-mesh or 2-mm screen are dispersed by stirring for 10 minutes with 100 cc of a normal solution of ammonium acetate, pH 7.07. Complete details on the preparation of this solution have been given by Schollenberger (4). To facilitate the filtration of the soil suspension, especially in the case of clay soils, filter paper pulp is added to the suspension before the dispersion. This pulp prevents the formation of an impervious mass. The soil suspension is filtered on a 10-cm Buchner funnel with suction into a clean filter flask and washed with an additional 100-cc portion of ammonium acetate solution. The soil on the filter should never be allowed to become dry before washing with the acetate solution. Calcium is determined in the filtrate by precipitation with ammonium oxalate and subsequent titration with N/5 $KMnO_4$

The amount of exchangeable calcium in soils as determined by the dispersion and leaching methods is given in Table 2. These results show a close agreement between the two methods Excellent checks between duplicate determinations were obtained in the dispersion method. Since all of the soil aggregates are broken apart by the dispersion, the soil sample is fairly uniform. In the leaching method there may be considerable variation in the size of aggregates in duplicate samples of the same soil which would tend to give different results.

Practically complete replacement of calcium is obtained by one dispersion, although there is a tendency for a small amount of exchangeable calcium to remain in the soil, as might be expected. However, this quantity is so small as to be negligible for most purposes. The effect of stirring the dispersed soil with additional portions of the salt solution upon the soluble and exchangeable calcium is shown in Table 3. The two soils used in this study are widely different in their nature. The Crosby silt loam (calcareous horizon) contained 16.0% carbonates with a reaction of pH 8.20. The Wooster silt loam from the unlimed end of fertility plats contained only 0.012% carbonate and had a reaction of pH 4.85.

The amount of exchangeable calcium obtained in the first dispersion represents the quantity of calcium as determined by the procedure given above. The other amounts represent successive treatments of the filtered soil with 75 cc of ammonium acetate solution. The soil was filtered after stirring with the additional acetate solution but was not washed. It is readily seen that most of the exchangeable calcium is removed by the first treatment. The constant results after the

TABLE 3.—*Effect of successive treatments on the soluble and exchangeable calcium in soils.*

	Dispersed, washed with 100 cc CH_3COONH_4	Stirred with successive 75-cc portions of CH_3COONH_4 1	2	3	4	Carbonates %	pH
	Crosby silt loam (calcareous layer, 30–36 inches)						
Per cent	0.405	0.066	0.059	0.062	0.062	16.0	7.65
M. E.	20.24	3.28	2.96	3.12	3.12		
	Wooster silt loam (unlimed surface)						
Per cent	0.0274	0.0024	0.0008	—	—	0.012	4.85
M. E.	1.37	0.12	0.04	—	—		

TABLE 4.—*Effect of successive washings on the soluble and exchangeable calcium of Crosby silt loam (calcareous layer, 30–36 inches).*

	Dispersed with 100 cc CH_3COONH_4 (not washed)	Washed with successive 50-cc portions of CH_3COONH_4 1	2	3	4
Per cent	0.4104	0.074	0.056	0.058	0.050
M. E.	20.52	3.68	2.80	2.88	2.48

second treatment in the Crosby silt loam may be interpreted as being due to the solubility of the carbonates. This solubility amounts to about 3.12 m.e. of calcium under the conditions of the experiment. A slight amount of exchangeable calcium is obtained in a second treatment of the Wooster silt loam. Since the dispersion method requires a much shorter time for obtaining the exchangeable calcium than extraction by leaching, the solubility of carbonates should tend to be less in the dispersion method.

In order to determine the effect of successive washings on the soluble and exchangeable calcium, 25 grams of the Crosby silt loam were dispersed with 100 cc of normal ammonium acetate solution, filtered, and washed with 50-cc portions of acetate solution. The results, given in Table 4, show that the second 50-cc portion evidently removed all of the exchangeable calcium. The solubility of carbonates appears to be about 2.8 m.e. of calcium under these conditions

The dispersion method should be an aid in the determination of the other exchange cations in the soil as well as the calcium ion. It should prove especially useful in base exchange studies where a large number of determinations are to be made.

CONCLUSIONS

Mechanical dispersion provides a means for shortening the time involved in the determinations of the lime requirement of soils by the Jones and Hopkins methods and in measuring the amount of exchangeable calcium in soils. Dispersion should also be applicable to other chemical studies of soils.

The advantages of the dispersion method for making these determinations are:

1. By breaking down the soil aggregates an ideal condition is presented for a thorough contact between the soil and the chemical reagent used. As a result of this, equilibrium is more readily attained.

2. Dispersion followed by washing the soil with the salt solution used results in the release of the total acidity capable of being produced by the reaction of a salt solution, thereby eliminating the use of the factor employed in the ordinary Jones and Hopkins method.

3. The soil extract from heavy clay soils can be obtained in a much shorter time than in the leaching method.

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NOTE

PRODUCING SEED CORN OF VARIETAL CROSSES

For the past two years tests have been under way to determine the value of a number of different varietal corn crosses. A number of these seemed good enough to warrant extensive farm trials. Accordingly, steps were taken to produce some seed in a small but commercial way. The plans and results are briefly set forth herewith in the hope that they may prove of interest.

The cross of Quebec No. 28 x Stowell's Evergreen appeared to give the greatest promise from the standpoint of ensilage production. These two varieties represent extremes in type. Quebec No. 28 is a 12-rowed yellow flint corn coming from a strain that has been grown in this Province for upwards of 100 years. It is, therefore, quite early, under our conditions, ripening in approximately 100 days In stature it attains a height of only about 6 feet. Like practically all flints it tillers freely and on reasonably good soil will produce one or more fair ears on the tiller shoots Stowell's Evergreen is a sweet corn and has the characteristic growth habits of that type It is so late in maturity that seed must be secured each year from the warmer sections in Ontario

The actual plan of planting adopted was as shown herewith, where rows marked "A" represent the ♂ parent and those marked "B" represent the ♀. Extra rows of the ♂ parent were planted on the west, since the prevailing wind came from that direction during the ten days or two weeks that pollen was shedding. Owing to the wide difference in time of maturity, it was necessary to plant the two sorts at different dates. Accordingly, the Quebec No. 28 was not planted until the Stowell's Evergreen was above the ground. The latter was planted on May 26 and the former on June 11. Both varieties were planted in hills 3 feet apart each way and thinned to four stalks per hill. All of the "B" rows were kept thoroughly detasseled.

The total area of the block was only 0.277 acre. The system of planting employed allowed 59% of the land to be occupied by the ♀ parent or hybrid seed-producing plants and 41% by the ♂ parent.

The set of seed on all the "B" rows was perfect or practically so, indicating an ample supply of pollen to effect complete fertilization. Stowell's Evergreen is a heavy pollen producer and its heavy tillering habit helps further to extend the period of pollen shed.

The yields from each of the "B" rows was determined separately. No significant differences were noted in the filling or yields from different rows. This would further indicate abundance of pollen.

Samples were drawn from each row and their dry matter and shelling percentage determined. On this basis the yield was calculated for corn of 15% moisture as follows:

Total yield from block	9.61 bushels
Yield per acre (including land occupied by "A" and "B" rows)....	34.33 bushels
Yield per acre (calculated only on the "B" rows)	58.67 bushels

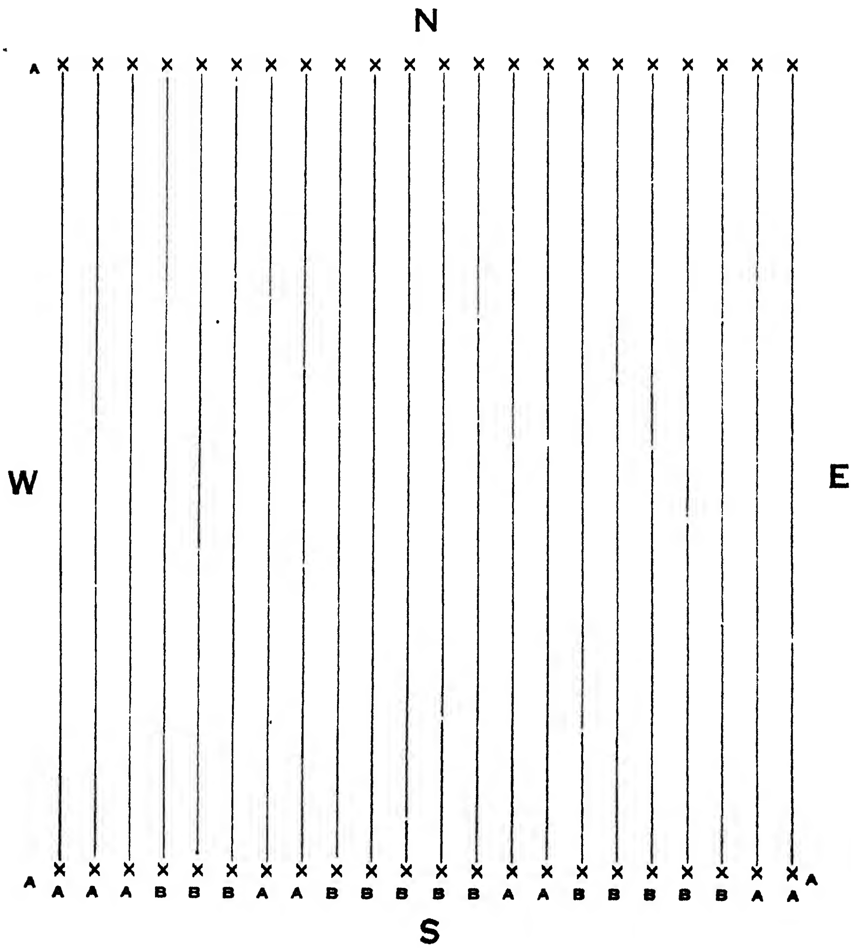

FIG. 1.—PLAN OF 1927 PLANTING FOR HYBRID SEED PRODUCTION.

A rows = ♂ or pollen parents (tassels left on).
B rows = ♀ or ear parents (detasseled rows).

The crop was harvested on October 10 when the danger of a killing frost was iminent. A number of light frosts had already occurred but none of sufficient intensity to injure the grain on the cob.

From the actual results obtained and from observations made during the development of the crop several changes in the plan of planting suggest themselves. There does not seem to be any particular advantage in planting the ♂ parent in double rows in the body of the block. In future the ♂ will be put in as single rows with the exception of the west side. Results further indicate that some reduction, at least, may be made in the proportion of ♂ and ♀ rows. It is proposed for the present season (Fig. 1) to plant north and south and to alternate one row of the ♂ with three of the ♀. With two border rows of the ♂ on the west and one row on the other three sides this will work out to approximately 75% of the block being devoted to hybrid seed production and should thereby increase the yield of that class of seed.—L. C. RAYMOND, *Assistant Professor of Agronomy, Macdonald College, Quebec, Canada.*

BOOK REVIEW

TRUCK CROP PLANTS

By Henry A. Jones and Jos. T. Rosa. New York: McGraw-Hill Book Co., XIV + 538 pp. illus. 1928. $5.

This book is a scientific discussion of vegetable plants. It is well adapted for a college text book, for which purpose it is evidently intended. It contains much scientific information that would be difficult for the average student to find easily

In this text the botany (taxonomy, morphology, and physiology) of vegetable crops is especially emphasized. The crops are arranged and discussed by botanical families, and the growth and development of each vegetable is traced from the standpoint of the morphology of the crop and of plant physiology. In addition, the marketing of each crop and the control of its insect pests and diseases are also included. (C. B. S.)

AGRONOMIC AFFAIRS

MEETINGS AND WORK OF AGRONOMY RESEARCH COMMITTEE OF THE SOUTHEASTERN STATES

The station agronomists of the southeastern states after a preliminary meeting in Atlanta a little over a year ago effected an organizaton of themselves to be known as the Agronomy Research Committee of the Southeastern States, with J. C. Pridmore, Director of the Southern Soil Improvement Committee of the National Fertilizer Association, and Dr. J. J. Skinner, of the Federal Bureau of Chemistry and Soils, as members.

The purpose of the committee is to devise carefully plans for new cooperative research work in soil fertility and other agronomy lines of economic importance to the South and to coordinate, so far as possible, the work now in progress in this territory.

During the past year, four meetings (three in Atlanta and one in Memphis) have been held with practically a full attendance of the membership of the committee. In addition to agreeing upon the outlines for three cooperative soil fertility experiments which are being or will be conducted this year in a number of the cotton belt states, it has agreed upon uniform general fertilizer recommendations for cotton for most of these states which are as follows:

FERTILIZER ANALYSES FOR COTTON RECOMMENDED BY THE AGRONOMY RESEARCH COMMITTEE OF THE SOUTHEASTERN STATES

For the extreme northeastern section of the cotton belt, including southeastern Virginia and northeastern North Carolina: 12-4-4 on the heavier types of soil which normally produce a rank vegetative growth, making early maturity an essential factor; and 10-6-4 for the lighter types of soil where vegetative growth is small to normal, indicating a need for nitrogen.

For the Central Coastal Plain section which includes eastern North and South Carolina: 10-4-4 on the heavier types of soil which normally produce rank vegetative growth, making early maturity an essential factor; and 8-5-3 or 8-4-4 for the lighter types of soil where vegetative growth is small to normal, indicating a need for nitrogen. On the lighter types of soil in this region, the use of from 18 to 30 pounds of ammonia per acre from readily available material is recommended as a side application to be applied at the first cultivation after chopping.

For the Piedmont section of North and South Carolina and Georgia: 10-5-3, except on the sandier soil types where the potash should be increased to 4 or 5%. On the less fertile soils of this region, the use of from 18 to 30 pounds of ammonia per acre from readily available materials is suggested as a side application to be applied at the first cultivation after chopping.

For the Coastal Plain of Georgia: 9-3-5 for the dark pebbly soils of heavy character and 9-3-8 for the sandier and lighter phases of this nature; 8-4-4 for the gray sandy soils; and 10-4-4 for the red and brown soils. For the light porous soils of this region, the use of approximately 18 pounds of readily available ammonia per acre is recommended as a side application to be applied at the first cultivation after chopping.

For the hill and flat woods sections of Mississippi: 8-6-4 or 8-4-4.

For the prairie sections: 8-8-0 except where rust prevails, then 8-8-4 is recommended.

For Mississippi Delta: 25 to 30 pounds of nitrogen alone; where rust prevails, apply 24 pounds potash per acre in addition to nitrogen.

The rate of application necessarily varies with conditions. For general use, 600 to 800 pounds per acre is advocated.

Where it is desired to use a higher analysis fertilizer, multiples of these ratios should be used. For example, a 12-6-6 my be substituted for an 8-4-4, using proportionately smaller quantities.

The meetings of the committee have thus far been quite fruitful and the members of the committee are generally optimistic as to the future possibilities of its labors.

The committee is at present constituted as follows: C. B. Williams, North Carolina, *Chairman*, C. B. Anders, Mississippi, *Secretary;* M. J. Funchess, Alabama; T. S. Buie, South Carolina; R. P. Bledsoe, Georgia; C. A. Mooers, Tennessee; W. E. Stokes, Florida; W. J. Davis, Georgia; T. B. Hutcheson, Virginia; J. J. Skinner, Bureau of Chemistry and Soils, Washington, D. C.; and J. C. Pridmore, Soil Improvement Committee, National Fertilizer Association, Atlanta, Georgia.

CONFERENCE OF BRANCH EXPERIMENT STATION WORKERS

The fourth annual conference of branch experiment station workers held at Manhattan, Kansas, February 24 and 25 was attended by L. C. Aicher, A. L. Hallsted, R. E. Getty, and A. F. Swanson from the Hays Station; B. F. Barnes and J. B. Kuska from the Colby Station; F. A. Wagner and E. H. Coles from the Garden City Station; T. B. Stinson from the Tribune Station; and I. K. Landon from the Southeast Kansas Experimental Fields. Those attending from neighboring states were, L. L. Zook, North Platte, Nebraska, and John Carter, Jr., Clayton, New Mexico.

In a section of the conference devoted to new crops a variety of white-seeded sorghum especially resistant to lodging was named Atlas, and was approved for distribution to a few men who will produce a supply of seed under the supervision of the station.

Plans were discussed for final tests of varieties of barley prior to distribution of a superior sort. The results of experiments with Hays Golden corn, which were reviewed, indicated that this variety is about equal to the best white variety and superior to other yellow varieties in central and western Kansas.

Experimental data from five stations showed a high correlation between soil moisture at seeding time and the yield of the following crop of wheat. The results indicated the desirability of knowing the amount of moisture in the soil at seeding time and suggest the possibility of using this information in a practical way to vary the acreage of wheat, depending upon the chances for a profitable crop.

SUB-COMMITTEE ON SOYBEAN REGISTRATION

At the annual meeting of the American Society of Agronomy held in Washington, D. C., November 1926, the Society approved a general plan for the registration of varieties of merit for other agronomic crops when such registration appeared desirable to the members of the Committee on Varietal Standardization.

Investigators of soybean improvement have asked for the appointment of a committee to register soybean varieties. With the approval of the president of our Society, A. G. McCall, the following subcommittee has been appointed: W. J. Morse, office of Forage Crop Investigations, U. S. Department of Agriculture, *chairman;* C. M. Woodworth, Illinois; and J. W. Zahnley, Kansas.

The actual details of registration will be handled by M. A. McCall of the Office of Cereal Crops and Diseases, U. S. Department of Agriculture, who will act as registration officer.

VARIETAL STANDARDIZATION COMMITTEE
H. K. Hayes, *Chairman*
L. H. Newman
E. F. Gaines
J. H. Parker
R. G. Wiggans

NEWS ITEMS

D. W. ROBERTSON of the Department of Agronomy of Colorado Agricultural College has been on leave of absence at the University of Minnesota, working toward his doctorate.

C. E. CORMANY, for the past eight years Assistant Professor and Research Assistant in farm crops at Michigan State College, has accepted a three-year assignment as Agronomist for the Republic of Colombia, South America. Prof. Cormany left for Bogota about February 1. Prof. H. C. Moore, potato specialist of the Farm Crops Department, will take over the teaching work in potatoes formerly handled by Prof. Cormany.

L. D. Kurtz, Extension Specialist in Farm Crops, Michigan State College, accepted a position as specialist in charge of crops extension at the Montana Agricultural College on February 15. Prof. Kurtz will take over the organization built up by Prof. Ogaard when the latter enters upon his new duties as Secretary of the Farm Seed Association of North America. Prof. Kurtz has had an active part in the alfalfa campaigns in Michigan which have been an important factor in increasing the acreage of alfalfa in the state from 74,000 acres cut for hay in 1919 to 513,000 acres in 1927. Prof. Paul Miller, of the Farm Crops Extension staff of Michigan State College, will assume the leadership of the Michigan alfalfa projects formerly handled by Prof. Kurtz.

A new greenhouse has just been completed at the West Virginia Agricultural Experiment Station to be used for agronomic investigations.

Pallempati Gopala Krishna and Ivan Francis Phipps, who completed work for Ph.D. degrees at Cornell University in February have left for their respective homes via England. The former is from Pickett Secunderabad (Deccan) India and the latter from Waite Research Institute, University of Adelaide, Australia. Both did their major work in agronomic lines.

In Saskatchewan the term "Field Husbandry" is used as being synonymous with the term "Agronomy" as it is used in the United States. The Field Husbandry Department of the University of Saskatchewan, located at Saskatoon, has issued a set of bulletins dealing with various subjects of interest to Saskatchewan farmers and Great Plains agronomists, as follows: Flax Production in Saskatchewan, Barley Production in Saskatchewan, Rye Production in Saskatchewan, Alfalfa Production in Saskatchewan, Summer Fallow Substitutes for Saskatchewan, Rainfall Records for Saskatchewan, Meadows and Pastures for Saskatchewan, Sunflower Production in Saskatchewan, Field Husbandry Investigations in Progress, Leading Varieties for Saskatchewan, Sweet Clover in Saskatchewan, Potato Growing in Saskatchewan, Wheat Production in Saskatchewan, and Oat Production in Saskatchewan.

N. A. Pettinger, who completed work for the doctorate at the University of Illinois in June, 1927, was appointed Associate Agronomist in the Virginia Agricultural Experiment Station to replace Dr. T. K. Wolfe who resigned to become Managing Editor of *The Southern Planter*.

George W. Patteson, Extension Agronomist of the Virginia Agricultural Experiment Station, resigned January 1, 1928, to accept a position with the Chilean Nitrate of Soda Educational Bureau. Mr. William H. Byrne, Assistant Extension Agronomist, has been promoted to fill the vacancy, and Mr. Samuel Preston, County Agent for Rappahannock County, Virginia, has been appointed Assistant Extension Agronomist.

D. A. Brown, Assistant Field Husbandman on the Morden Dominion Experimental Farm, has accepted the position of Manitoba Supervisor of the Illustration Stations, with headquarters at the Dominion Experimental Farm, Brandon, Manitoba

J. D. Guild, Manitoba Supervisor of the Illustration Stations, has resigned to become a member of the Agricultural Department of the Canadian National Railways, with headquarters in Winnipeg

A. T. Elders, who has conducted the cytological investigational work in the Department of Botany at the Manitoba Agricultural College, has been appointed Agrostologist on the Dominion Experimental Farm, Brandon, Manitoba. Mr Elders is equipping a cytological laboratory at this station and will do most of the cytological work for the western Dominion stations.

Plans are under way and work will soon begin on the remodeling of one of the University buildings and the equipping of laboratories for experimental work in agronomy at the University of Vermont. It is expected that the laboratories will be ready for use by fall and that experimental work will begin at once.

The Department of Farms Crops and the Department of Soils at the Washington State College have been consolidated into a new Department of Agronomy. Professor E. G. Schafer, head of the Department of Farm Crops for fifteen years, has been made head of the new Department of Agronomy.

S. C. Vandecaveye, head of the Division of Bacteriology of the Washington Agricultural Experiment Station since 1924, has been promoted to Professor of Soils in the Washington State College and Soil Biologist of the Experiment Station.

Lewis W. Erdman, formerly Associate Professor of Soils and Assistant Chief of the Department of Soils at Ames, Iowa, began his duties as Professor of Soil Technology at the University of Maryland on January 1, 1928.

C. M. SLAGG, Chief, Tobacco Division, Central Experimental Farm, Ottawa, Canada, and formerly at Windsor, Connecticut, resigned on January 15 to become Director of Tobacco Investigations in Australia.

H. A. FREEMAN, Superintendent, Dominion Experimental Farm, Harrow, Ontario, resigned on January 31 to become manager of the Ontario Tobacco Plantations, Limited, Simcoe, Ontario.

H. W. E. LARSON, Research Fellow in Soils at the Oregon State Agricultural College, has accepted a position as Research Assistant in Soils at the University of Saskatchewan, Saskatoon, Canada. Prof. Larson will make a special study of chemical and other characteristics of soil profiles.

C. V. RUZEK, Associate Professor in Soils, Oregon State Agricultural College, has been granted sabbatical leave for the year beginning June 1, next Prof. Ruzek will probably spend the time in study at the University of Wisconsin

A. P. GIANINI, president of the Bancitaly Corporation and a high official of the Bank of Italy, has recently given to the College of Agriculture of the University of California the sum of $1,500,000 for the general purposes of research and the dissemination of knowledge in the field of Agricultural Economics. A portion of the gift, not to exceed $500,000, may be expended for the erection of a building and the regents are given broad discretion in the expenditure of the remainder. One point of significance that attaches to this gift is that it is believed to be the first gift of considerable magnitude from a private source for the endowment of agriculture.

J. W. GILMORE, Professor of Agronomy, College of Agriculture, Davis, Calif., was recently elected a member at large of Pi Gamma Mu, the national honorary society for the Social Sciences. Thus, Agronomy is given recognition as having a bearing upon the general welfare of society.

THE first notice has been sent out for the meeting of the Pacific Division of the American Society of Agronomy to be held at Davis and Berkeley, Calif., from June 19 to 21. The first day will be spent at Davis, and on the way to Berkeley. The other two days will be spent at Berkeley and the dinner will take place there on the evening of the 20th.

VICTOR E. SPENCER, Assistant in Soil Fertility at the University of Illinois, has been appointed Associate Professor in Soils Research at the University of Nevada, effective April 1.

F. M. Willhite has resigned his position as Assistant in Soil Survey Analysis at the University of Illinois in order to engage in business at Columbia, Missouri.

W. W. Burr, Chairman of the Agronomy Department and Vice-Director of the Agricultural Experiment Station of the University of Nebraska, has been promoted to the position of Director of the Agricultural Experiment Station and Associate Dean of the Agricultural College. He retains the position of Agronomist. This advancement accompanies the appointment of Dean and Director E. A. Burnett to the Chancellorship of the University of Nebraska.

During the month of March the Extension Division of the North Dakota Agricultural College sponsored a series of eight regional economic conferences in North Dakota. At each of these conferences basic data of an agronomic character in regard to each of the important agricultural crops raised in the state was placed in the hands of a group of selected farmers. These farmers organized themselves into commodity committees and, after discussing the data, brought in recommendations which were adopted by the entire conference. These recommendations covered such things as desirable varieties, desirable cultural methods, relative acreage proportions, etc.

CORRECTION BY R. J. GARBER

Since the publication of the paper entitled, "Size of Plat and Number of Replications in Field Experiments with Soybeans" in this Journal (Vol. 20: 93–108), the author's attention has been called to an apparent oversight in dealing with the comparison of the variability obtained by systematic and random replication.

The standard deviations as obtained for this comparison are based on the mean yield of the plats in any replication. The comparison should more justifiably have been made on the variability of the individual plats. In view of this the wording of the last sentence in the second paragraph on page 104 should be changed so that it will read as follows:

"This indicated that systematic and random sampling, particularly where a small number of replications were used, did not give the same index of variability in the field as measured by the standard deviation."

On page 108, lines 16 and 17, there should be substituted for the words "too small" the following, "different from those calculated from random sampling."

JOURNAL

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SYMPOSIUM ON "FIELD EXPERIMENTS"

Leader: E. L. WORTHEN, Cornell University

1. The Type of Problem Adapted to Field Plat Experimentation. Charles F. Noll, Pennsylvania Agricultural Experiment Station.
2. Planning the Plat Experiment. H. H. Love, Cornell University.
3. The Mechanical Procedure of Field Experimentation. T. A. Kiesselbach, Nebraska Agricultural Experiment Station.
4. Mathematics in the Service of Agronomy. J. Arthur Harris, University of Minnesota.
5. Application of Plat Results to Agricultural Practise. E. L. Worthen, Cornell University.

1. THE TYPE OF PROBLEM ADAPTED TO FIELD PLAT EXPERIMENTATION[1]

CHARLES F. NOLL[2]

Field plat investigations entailing a vast expenditure of time and money are now under way at most, if not all, of our 60 or more agricultural experiment stations. This type of investigation was instituted at the very organization of these institutions and even now at many experiment stations constitutes a large part of the investigational work in crops and soils.

Plat investigations usually imply testing for yield with carefully measured areas of land. However, plats may be so laid out chiefly to

[1]Paper read as part of the symposium on "Field Experiments" at the meeting of the Society held in Chicago, Ill., Nov. 18, 1927. Contribution from the Department of Agronomy, Pennsylvania Agricultural Experiment Station, State College, Pa. Published by permission of the Director as Technical Paper No. 447.

[2]Professor of Experimental Agronomy.

insure exact applications of the treatments where ends other than yields are sought. Along with the yields the investigator usually is interested in securing other information, as in the case of variety tests in quality and in general adaptability as indicated by hardiness, time of maturity, resistance to diseases, stiffness of straw in small grains, etc.

All thoughtful agronomists will acknowledge the limitations of plat work which are inherent from their very nature. The most serious are that the experiments must be made under constantly changing conditions, as of moisture and temperature, and that the average results for a given soil in a given locality, no matter how carefully obtained, are not necessarily applicable elsewhere. Only by conducting the tests under different conditions can general rules for practise be deduced. It is acknowledged that plat work has not been productive of scientific principles.

In this connection it may be well to call attention to the fact that we may not have made the most of the opportunities offered by plat work. Careful studies of the differences in climate and in the soil where similar tests are made under unlike conditions may reveal the underlying causes of differences in the results. Field plat work in connection with soil treatment investigation offers opportunities for chemical and other laboratory studies. At some of the experiment stations such investigations have contributed fundamental knowledge on the processes going on in the soil, upon the biology of the soil, and upon the fate of the fertilizers and amendments applied. Only a part of the possibilities are realized if only the yields are secured.

The Rothamsted experiments are famous not so much for the differences in yield secured as for the more fundamental data. Hall (1),[3] in the preface to his book on the Rothamsted experiments says, "Experiments which aim only at ascertaining how to derive the greatest monetary return from a given crop, however necessary they may be, are only of value for a short time and for the particular soil and locality where they are carried out." The great aim of the Rothamsted field experiments is to find out why certain results are secured rather than to find the combination of treatments that are the most profitable. Unfortunately, at most of the experiment stations we have not been able to report more than the results in crop yields.

I am of the opinion that, though we must recognize the limitations of field plat investigations, we do not know a better way of getting the knowledge we need, either in relation to the so-called crops questions

[3]Reference by number is to "Literature Cited," p. 425.

such as the merits of varieties nor to the soils problems such as are concerned with the building up and maintaining the productivity of the soil.

Chemical determinations of the quantities of the plant food materials present in the soil, except in soils unusually low in phosphoric acid or potash, have not indicated what should be applied for profitable increases in yield, though they have been useful as soil inventories. Likewise, attempts to determine available plant food elements by weak solvents have not given information that could be used as a guide to practise.

The various lime requirement determinations seem the most directly applicable, but should be interpreted in relation to individual soils. For example, in the extensive lime investigations carried on by White (2) at the Pennsylvania Experiment Station, it was found that red clover failed on fertile Hagerstown soil where the Veitch lime requirement was about 3,500 pounds of carbonate, while on Volusia soil good clover could be grown where the lime requirement was 7,000 pounds. In the light of such results we must be careful in our lime recommendations.

Pot and water culture studies of fertilizer needs have not been very dependable from the standpoint of their practical application. Hopkins (3) called attention to what he styled the almost perfect disagreement between short time paraffin pot and water culture tests and the yields actually secured on certain fertilizer plats at the Ohio Experiment Station. However, later pot tests conducted elsewhere in which the crops were grown more nearly to maturity have shown better agreement with the field results.

It may be of interest here to note that in a fertilizer test for apples at the Pennsylvania Experiment Station (4), in which the trees were grown for six years in metal cylinders 5 feet in diameter and 5½ feet deep and fertilized only for the last three years, the results paralleled those secured in orchard plats which ran for 18 years. In the latter the treatments did not show differentiating results until the trees were 12 to 14 years old.

Until we can examine a soil chemically or otherwise or test it by pots or cylinders or study the composition of the plants and then be able to direct farm practise, we shall be obliged to make field tests. It is not improbable that such short-cut methods for determining fertilizer needs will be devised; but if they are, it would still seem imperative to maintain plat experiments for their demonstrational value. It is not likely that we can ever determine the relative merits of strains, varieties, or species of crops by other than actual tests

in the field, though such particular qualities as susceptibility or resistance to disease can be investigated in other ways.

CLASSIFICATION OF PROBLEMS FOR FIELD CROP INVESTIGATIONS

I find it difficult to define the type of problem that should be studied by field plat investigations. Such problems are those in which the results are conditioned by the field environment. When a problem can be investigated under controlled conditions, it would seem as if it should not be a subject for field plat tests. Field plat tests are usually characterized by an effort to get relative yields, but as indicated before, more fundamental questions may be in the mind of the investigator. Below is an attempted classification of subjects for field plat studies. There is nothing original in this since it is only an attempt to list the various types of investigations which are now rightfully carried out in field tests.

TESTS OF STRAINS, VARIETIES, AND SPECIES

This may include, besides the usual testing of strains, varieties, and species, the crops grown in mixtures, such as barley and oats, or the various combinations of forage crops for hay or pasture.

One can hardly conceive of any other way in which relative merits of field crops can be determined except by observing them under field conditions.

CROP ROTATIONS

This may include the different series constituting the rotations and the sequence of crops in the rotations, as they have a bearing on yields, monetary value, and the control of weeds, insects, and diseases.

CULTURAL STUDIES

This may include the time and manner and, in some cases, frequency of performing the field operations.

FERTILITY TREATMENTS

These are efforts to determine:

(a) The needs for nitrogen, phosphoric acid, potash, or other fertilizer elements; the relative merits of the different carriers; the best combinations; and the most economical amounts to use.

(b) The best time and method of application.

(c) The best ways to supplement farm manures.

(d) The value of cover crops and green manures.

(e) The importance of lime, the forms to use, and the amounts and methods of application.

PASTURE INVESTIGATIONS

Besides the problems concerned with seeding and fertilizing new pastures and the methods of renovating old pastures, we may have studies on influences of methods of grazing. I believe such investigations are complete only when the results are measured in livestock returns.

In conclusion, I believe we shall always be obliged to use field tests to determine the merits of different crops or of varieties and that we could also profitably extend soil treatment plats to all the leading soil series or climatic regions of the respective states. On the other hand, I am sure that the advancement of the science of agriculture, as it pertains to crop production, will come chiefly from investigations in genetics, plant pathology, plant physiology, physics, and chemistry.

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2. PLANNING THE PLAT EXPERIMENT[1]

H. H. LOVE[2]

When planning a plat experiment there are many factors to be considered. First is the purpose of the experiment. Is it to be an experiment to measure the effect of different kinds and amounts of fertilizer, an experiment in cultural methods, or is it to be, perhaps, a variety test?

The different kinds of experiments will have different requirements so far as the layout is concerned. The variety test or cultural experiment will be in the nature of a short-time experiment, while one measuring the effect of fertilizer must naturally be continued for a long time. Whatever the experiment, it is necessary to use care in the selection of the field.

SELECTING THE FIELD

In choosing a field one should, if possible, select one that has had uniform treatment, that is, one which has had the same management with respect to rotation and varieties. While we know that no really uniform field exists, we should, so far as possible, select one which shows a small amount of heterogeneity. One should also know that the field has adequate drainage so that after the experiment has been started it will not be necessary to interrupt the work to put in drains. If the field is to be drained after it has been selected, then careful thought must be given to the placing of the drains, both as to mains and laterals. This must be done in relation to the size and shape of plats, which will be considered later. The field chosen should also be one for which the air drainage will be as uniform as possible. Proximity to orchards, woods, or large buildings should be avoided where possible. Difference in air drainage may affect the temperature and evaporation so that all plats will not be equally influenced.

Since the requirements of fertility experiments, so far as size of plat is concerned, are different than for certain variety tests, they will be considered first.

LAYING OUT THE PLATS

After the field has been selected and the matter of drainage settled, we are ready to lay out the plats. The question may arise as to whether we should run a blank test or a preliminary cropping test.

[1]Paper read as part of the symposium on "Field Experiments" at the meeting of the Society held in Chicago, Ill., Nov. 18, 1927. Paper No. 157 from the Department of Plant Breeding, Cornell University, Ithaca, N. Y.

[2]Professor of Plant Breeding.

This is a point upon which all may not agree. It seems, however, that much is to be said in favor of such a test, especially for long-time experiments. A blank test does take time and we all know how anxious most investigators are to begin the experiment. Also, we are not unmindful, in some instances, of the pressure from station directors and boards of control for results. In fact, promotions may be dependent on published results, sometimes with apparently little regard for their value. In spite of the possible objections, I would advocate blank tests, especially for fertility experiments which may run for years, and would also urge them for other experiments as well.

The question now arises as to how long the blank tests shall be run. No definite information is available and we have only judgment to guide us. The plan that seems worthy of trial is to lay out the plats in the shape that is to be used and then, having decided the rotation system to be followed, continue the blank test through at least one complete rotation. I feel that to be reliable it should be carried through two complete rotations. By this is meant the rotations of average duration, or from four to six years. This, I admit, takes time, but what is eight or ten years in preparation for plats that are to be continued for perhaps a hundred years? The blank test to be adequate should be continued long enough to cover a cycle of seasons.

Some may argue that the nature and variability of the plats may be determined by using certain crops, such as oats or wheat, rather than to use all that will appear later in the complete rotation. This does not seem worthy of recommendation, since the several crops may bring to light certain facts that will not be apparent in one particular crop.

What will be gained by such a blank test? This test, carefully conducted, will detect the good and poor spots in the field and indicate to some extent whether the change in fertility from one part of the field to another is gradual or abrupt. Such information will be of great aid in locating treatments, control plats, and the like, and also in interpreting the results.

What objections may be raised? There may be several of doubtful validity. The time required for such a test is one important objection that must be given consideration, but it seems in the light of the results from many hurried-into-experiments that those who are thoughtful are ready to meet this objection. Why should we be willing to conduct experiments which we feel will prove little, and be unworthy stewards of the public moneys entrusted to us?

Another objection raised is that the results may be of little use since we do not know that the relative fertility of the different plats will

continue, and that after the treatment is begun all may be changed. This suggestion bears investigation. We, who in the last quarter of a century have seen so many things demonstrated and proved which our forefathers said could never be, should not be the ones to draw conclusions before the test is made. That is one of the things this Society can promote, and we should be willing to encourage an experiment of this sort so that for the planning of future experiments this information will be available.

Such blank tests will point out, if they exist, such inherent differences in the plats as is evident from the results of the old three-year rotation plats at the Illinois Experiment Station. Here, especially for the 100 and 300 series, the plats varied considerably, and those that later received the complete soil treatment were better, as measured by the yields during the preliminary comparisons, than the plat chosen as a check.

The difference that is found in the check plats for the old soil series at the Pennsylvania Experiment Station would also be revealed by such blank tests. In this series check plat 8 has given considerably higher yields than the other checks. The blank test would have indicated whether the contiguous plats 7 and 9 were inherently better.

Such information can be made very useful in planning the experiment and in the interpretation of the results.

SIZE AND SHAPE OF PLAT

The size and shape of plat must receive consideration. What is the best size and shape? In arriving at an answer one must consider the matter first from the theoretical and then from the practical standpoint. While it may be possible to determine for a certain condition what is the ideal thing to do, nevertheless it may call for such an outlay of time, labor, and money that it would be unwise to follow out the ideal.

Considerable attention has been given to the size and shape of plats and certain general conclusions may be drawn. For general field tests larger plats are more accurate than smaller ones, but with the same area of land greater accuracy is obtained by dividing the larger plat into several smaller ones. That is, five plats of 1/200 acre each, other things being equal, will give greater accuracy than one plat of 1/40 acre. Long, narrow plats that extend in the direction of the greatest variation are more reliable than shorter, wider plats or square plats. It does not follow that long, narrow plats are the most accurate regardless of the direction in which they run.

On many fields it is not possible to so lay out the plats that they will extend in the direction of greatest variation.

Border effect may also be an important factor in choosing the shape and size of plat. Square plats have a shorter perimeter than rectangular plats of the same area. Thus, for a 1/40 acre plat that is square, the perimeter is 8 rods, while for the same area 1 rod by 4, the perimeter is 10 rods. Thus it may be well to consider border effect in deciding the size and shape of plat.

Consideration should also be given borders in the layout. If long, narrow plats are chosen it will be found very desirable to arrange the entire series of plats, if possible, so that they will extend north and south to afford equal distribution of light and prevent effect of shadows. This will be especially important where treatment plats causing vigorous growth come next to check or control plats.

The mechanics of handling the plats will also play a part in determining their size and shape. Such details as plowing, preparing, adding the fertilizing elements, seeding, harvesting, and the like must be considered. For soil treatment experiments it is impossible to use extremely small plats, since the fertilizer added to one plat may be carried or washed on to another. To obviate this with plats of any size it is necessary to have sufficient border between plats, and it is best to have the land graded so that the borders are a little lower than the plats. The plats should be either small enough so that all seeding, harvesting, and the like may be done by hand, or large enough to permit the use of drills, mowers, and binders. The practise to be followed will be determined by the land and facilities available. Where possible it is best to have some plats that will simulate field conditions, and for the cultural and fertility experiments plats large enough to permit the use of some mechanical aids are to be recommended.

A size and shape that will permit of some mechanical aids and still be small enough, considering the land available, to permit of adequate replication, should be adopted. It has been stated above that it is better to have several smaller plats than one large one. This means that, generally speaking, replication leads to greater accuracy. To be sure, there are limitations to this statement. If in replication the land area required is so great that some of the plats extend on to a field of another type, then replication may increase rather than decrease variability.

Mercer and Hall[3] have suggested that plats of 1/40 acre be used

[3]MERCER, W. B., and HALL, A. D. The experimental error of field trials. Jour. Agr. Sci., 4:107–132. 1911.

with five plats for each treatment. It seems that where machinery is to be used long and narrow plats from 1/100 to 1/40 acre, with at least five plats for each treatment, are desirable. If, on the other hand, it is preferred that most of the operations be done by hand, then it is best to have much smaller plats, say from 1/1000 to 1/500 of an acre, and that these be replicated so as to have 10 plats, at least, for each treatment.

If small grains, grasses, or clovers are to be the only crops grown the smaller plats are satisfactory, but where corn or other large plants are concerned it is desirable to have the larger plats so that a sufficient number of plants may be grown to eliminate individual variability.

HANDLING THE PLATS

In passing, it may be well to point out that care should be exercised to see that all plowing and other preparation of the plats be done as nearly at the same time as is possible. Care should also be given to the seed used. All plats should be sown with seed of the same pure variety.

It is also important that a particular set of plats should not be used to conduct several kinds of experiments at the same time. For example, variety tests have been conducted on soil plats by extending the varieties across the soil plats. This should be avoided where possible. Again, other tests may be introduced that will have a profound effect on later crops, as, for example, mixtures of corn and soy beans and tests of like nature. Where possible, then, the use of plats should be restricted to the tests for which they have been planned. Separate plats should be arranged to solve the other problems that arise. It may also be pointed out that it is not wise to include pasturing in the rotation.

CHECK PLATS

Naturally, there arises a question as to check plats. Shall they be used? If so, how will they be treated in the series and how frequently shall they occur? In recent years there has been some discussion relative to the value of check plats and a disposition on the part of some workers to reduce the number. However, at present the tendency seems to be to include check plats and use them in interpreting the results. A change, however, seems desirable and is urged by some investigators. This change involves a treatment for the check plats so that they may be kept in a fair state of fertility. The old plan of having the checks receive no treatment did not give a fair measure of the fertilizing elements added to the other plats,

since the check would likely decrease in fertility rather rapidly and the gain for an element as indicated by comparison would be misleading. The purpose of all such tests is to be able to make certain recommendations to the practical man, and the check with no treatment does not represent average soil conditions. A better method is to have an occasional nothing plat and to have the regular check plats receive a treatment that will tend to maintain their fertility.

There is a difference of opinion as to the number and frequency of checks. It is impossible to have the checks so arranged that they may serve as an absolute check. That is, one cannot have the yield of the check and of a treatment for the same identical plat. It becomes necessary, then, to arrange the checks so that they will give a fair means of comparison and at the same time not add too much to the labor involved. The arrangement that seems to be satisfactory is to have every third plat a check.

These check yields may then serve as a means of evaluating the effects of different treatments by direct comparisons or by the grading method. The average of all checks in the field or the graded value of the two nearest checks may be used as the basis for comparison. A combination of the two may be used. Some evidence seems to indicate that for very small plats there is little difference between any of the methods. For the larger plats, however, the average of all the check plats is the least desirable method. The grading method using the results of the nearest checks is better, and a combination of the two methods seems to have some further advantages.

ARRANGEMENT OF PLATS

The arrangement of the plats may now be considered. Shall we follow a regular arrangement and then repeat the replicated series in the same order? Is it better that the location of each plat be determined by chance? It is certain that the aim of the experiment is results that have been obtained by random sampling or a random assortment. There are, however, other factors to be considered. When the plats are small and several replications are possible, it is very likely that by following a regular arrangement and then repeating in the same order the plats will be so located that they represent a random sample of the field. This regular arrangement has points in its favor over the chance arrangement. It permits of a simpler system of handling, note-taking, harvesting, and the like. It seems there is less chance of mixing the records than with any other system.

When arranging by chance the method followed is to number the plats and then place cards bearing the plat numbers in one box and cards representing the treatments in another. Drawing from the plat numbers one may draw, say, plat No. 21, then from the treatment set we may draw a card indicating that lime is to be added. Thus plat 21 would become a lime plat. This plan would be followed for the entire series. Even when using this system it would not be wise to follow the chance arrangement absolutely but some adjustment must be made. When this is necessary the plan ceases to be a chance arrangement.

The Latin square method, as suggested by Fisher,[4] is a plan for arrangement of plats to overcome the effects of soil heterogeneity. With this plan we imagine the field as made up of rows and columns, and the replications arranged in such a way that each variety or treatment occurs once in a row and once in a column; but its exact location is determined purely by chance. For ordinary practise it does not seem that this random arrangement has any advantage over the regular arrangement, especially when one has small plats and sufficient replications.

All of the foregoing discussion has dealt chiefly with plats for fertility and similar studies. For variety studies the method of using rod rows or some modification for small grains is now accepted by most workers as the best, especially when the rows are supplemented by plats sown under field conditions. For other than small grain crops some adaptation of the row system is now proving to be a good method of testing.

Competition may be a factor in some localities, but it is not universal and is easily eliminated where it does play a part. Since the row system is well known and each worker will need to develop his own modifications, it does not seem necessary to elaborate it here.

In closing, it seems pertinent to suggest that since this Society is so much interested in method, it might be worth while to consider some cooperative studies on methods for various kinds of tests.

[4]FISHER, R. A. Statistical Methods for Research Workers. London: Oliver & Boyd. 1925.

3. THE MECHANICAL PROCEDURE OF FIELD EXPERIMENTATION[1]

T. A. KIESSELBACH[2]

The object of most field plat experiments is to compare the performance of various crops or cultural practises in such a manner that the results will be applicable to farm practise. At the same time the equipment and procedure for carrying out the mechanical operations should be of a nature to facilitate rapid and accurate work. It is this phase of field plat experimentation that will be chiefly discussed in this paper.

In all of the operations of growing the crop and determining yields, the watchword should be to develop and maintain uniformity of conditions so far as the nature of the experiment permits. It is just as important to use good technic, within practical limits, in agronomic field experiments as in the chemistry or biology laboratory. In fact it is much simpler in these pure sciences to eliminate all variable factors, except those under investigation, than it is in field experiments. And yet no more important scientific and applied truths are established than in properly conducted agronomic tests.

Ten years ago a trained botanist remarked, as he observed the details of some agronomic field plat experiments, that he had been unaware that comparative yield determinations were so involved. He had thought all there was to a variety test was merely to plant, cultivate, harvest, and weigh the crop. The fact is that there are certain details of carrying out these operations which greatly affect the reliability of the results. Agronomists have come quite generally to recognize the broad principles of good field plat technic which have been compiled by various committees on the standardization of field experiments, and adopted by the American Society of Agronomy. The extent to which these principles may be carried out must depend upon the land, labor, and other facilities available. We should not attach greater significance to our results than the manner of conducting the work justifies. One tendency to be guarded against is to lose sight of large important issues in an endeavor to settle comparatively unimportant controversial points.

[1]Paper read as a part of the symposium on "Field Experiments" at the meeting of the Society held in Chicago, Ill., Nov. 18, 1927. Contribution from Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Neb., as paper No. 45, Journal Series. Published with the approval of the Director.

[2]Agronomist.

The chief topics meriting consideration in this paper would appear to be: (1) Preparation of the land for seeding; (2) preparation of the seed; (3) laying out the plats; (4) sowing the seed; (5) care of the growing crop; (6) harvesting the crop; (7) threshing or shelling the grain; and (8) determining the yields on a comparable basis.

PREPARING THE LAND FOR SEEDING

In the preparation of the land for sowing experimental plats provision should be made for uniform drainage and tillage wherever these are not the variable factors under investigation. Use of a two-way plow eliminates dead furrows and back furrows. All plats should be comparable as to time, depth, and conditions of plowing and other preparation treatments, since variation in any of these may materially affect yields. In order to overcome irregularity due to such treatments, the test plats should preferably extend crosswise of the main line of tillage.

PREPARING THE SEED

Comparative uniformity of seed distribution by the sowing machinery is facilitated through removal of foreign matter from the seed by the use of a fanning mill. Through lodging of grain in various parts of the mill, such equipment is a possible source of seed contamination. Thorough cleaning of the mill between different sorts is essential to prevent mixing.

In the case of seed which is infected with disease that may be controlled by treatment, such as the stinking smut of wheat, a disease control treatment should be applied. This holds especially true in comparative variety tests in which different lots of seed are brought together which may differ in the amount of infection. The reduction in yield of wheat has been found fairly proportional to the amount of stinking smut present in the growing crop.

Even where a single uniform lot of infected seed is used, failure to treat for such disease may result in a material error in certain cultural studies, such as time of sowing experiments, in which the conditions of growth are made to vary. It has been shown by a number of workers that the percentage of plant infection which results from sowing seed wheat carrying a given load of inoculum varies decidedly with the climatic conditions prevailing during early growth.

LAYING OUT THE PLATS

The character and arrangement of field plats must be determined in part by the amount and general nature of the land available,

the character of the crop to be tested, the general nature of the experiment, and by the type of sowing and harvesting machinery to be used.

It is generally recognized that comparatively long, narrow, replicated plats designed to avoid serious effects of border competition give best results. The arrangement of plats should be such as to distribute apparent or known systematic soil variations to the best advantage. The principle of chance distribution of varieties or treatments should be borne out, but in so doing the element of chance may be modified by intelligent placement.

To illustrate, in an extensive corn variety test it is advisable to arrange the varieties somewhat according to their probable vegetative size and earliness of maturity in order to facilitate normal pollination and also to reduce the degree of inter-plat competition between unlike sorts. Further, in a small grain variety test in which some varieties are ready to harvest in advance of others, it is advantageous to have them arranged in the order of their earliness. This avoids damage to the late-maturing plats by harvesting machinery. It has been found very convenient, in addition to such arrangement of the varieties, to insert discard plats of the same crop at intervals which may be used for down swaths in opening up the field at harvest.

The type of plat described as best from the standpoint of reliability is also best suited to the use of horse- or tractor-drawn implements. It is commonly advisable to have plat widths conform to the width of standard farm drills, planters, and harvesters. In the case of small grain, corn, and forage crops 7 feet or some multiple thereof serves as a very practical width. This fits the 7-foot disk, the 7-foot drill, the 7-foot binder, and the 3.5-foot corn planter and cultivator. The plat width naturally should be planned to best fit the particular experiment. For example, the equipment used and manner of handling forage makes a plat width of at least 14 feet desirable with such crops.

Plat areas ranging from 1/10 to 1/40 acre are recognized as standard. With satisfactory protection against undue border effects, the smaller plats are of sufficient size to carry a representative population. When land is available the larger areas may be given preference in permanent soil fertility, crop rotation, and seedbed preparation experiments, provided replication is not thereby sacrificed.

Plat organization with reference to reducing errors incident to border effects of dissimilar adjacent plat treatments is a recognized agronomic principle. There are three types of practical control measures. First, border rows may be removed and not included in

the harvested areas upon which yields are based. This is perhaps the most reliable of all systems. Second, since it appears desirable to have an uncropped strip between plats of closely drilled small grains or forage crops in order to denote their boundaries, it is proposed that the width of this strip be reduced to a minimum. If the crop is sown with a 7-inch drill, the omission of a single drill row leaves a space of 14 inches between the border rows of adjacent plats. This has proved sufficient space to operate the divider board of the binder or mower without crowding adjacent plats, and at the same time it is so narrow that border effects are not very marked. To be sure, the marginal rows are usually benefitted by the additional space available and for this reason the additional ground should be charged up to the area of the plat.

Without removal of the marginal rows of such plats the error as to relative yields consists primarily in the differential reaction of different plantings to this narrow bare strip, which is equivalent to allowing a total of 10½ inches space for each of the outside rows, instead of the usual 7 inches. By grouping varieties according to their vegetative type, this effect distributed over the entire 12 or more rows of the plat would seem to cause little need for concern as to the comparability of results. It is admitted that experimental data bearing upon this are insufficient and more should be obtained.

The Nebraska Experiment Station has each year in the neighborhood of 900 close drilled field plats, averaging 13 rods in length. Added together these make 36 miles of plats with 72 miles of marginal rows. If, through the means proposed, we can legitimately overcome the need for removal of the marginal rows before harvest, it would be a decided saving of hand labor and inconvenience.

Third, in the case of permanent fertilizer or seedbed preparation experiments, the plats sown to any one crop should be arranged serially and the insertion of a similarly cropped discard strip of 7 feet in width between plats is recommended. This is just the width of one binder swath, or two corn rows. Such a strip serves for making the adjustments between treatments and is the equivalent of discarding border rows. Before the small grain or forage crop has made much growth, the plat boundaries may be outlined by hoeing out marginal strips approximately 8 inches wide. This procedure is necessary since the grain is usually sown lengthwise of the series and crosswise of the individual plats. Such a narrow discard strip does not materially affect plat yields and yet facilitates harvesting without interference with adjacent plats.

SOWING THE SEED

A statement of the rate of sowing is commonly an important part of the description of any field experiment. The applicability of results of some experiments may depend upon the reliability of the calibration of the seeder. An occasional thorough checking up of seeding machinery in this respect is advisable. Maladjustments of grain drills may cause a discrepancy of several pecks of seed per acre. It is obvious that in a rate of sowing experiment it is important to know that when the drill is set for 5 pecks of seed per acre approximately this amount, rather than perhaps 3 or 7 pecks, is actually sown.

The amount of seed delivered through a grain drill set at a given volume is a rather variable quantity, since the rate of flow through the feed cups is affected somewhat by such factors as seed size and seed treatment. It is advisable to use seed of medium size for each specific crop in testing and adjusting the drill calibration.

The question now arises relative to adjusting the drill for varietal differences in seed size. It is evident that no machine can sow two varieties at equal weights, equal numbers, and equal volumes of seed at the same time. Fortunately, there may be considerable variation, within reasonable limits, in the rate of sowing without materially affecting the yield per acre. To illustrate, at the Nebraska Experiment Station where 5 pecks of Turkey wheat per acre is regarded as standard, the rates of 3, 4, 5, 6, and 8 pecks yielded, respectively, 22 2, 23.6, 23.7, 24.4, and 24.5 bushels per acre as an average for the last nine years. During the last 15 years, 1913 to 1927, two varieties of oats differing in seed size were each sown comparably at several planting rates. At the respective rates of 8, 10, 12, and 14 pecks per acre, the small-seeded variety Kherson yielded 44.0, 44.4, 44.3, and 43.5 bushels, while the large-seeded variety Swedish Select yielded 40.8, 41.8, 42.4, and 42.2 bushels per acre, respectively. The extreme difference in yield of these various rates was 0.9 bushel for the Kherson and 1.6 bushels for the Swedish Select. The latter responded slightly to somewhat thicker sowing than the former.

In the comparative variety trials at the Nebraska Station all varieties of oats are placed in two groups according to seed size, the smaller being sown at the rate of 10 pecks and the large seed at the rate of 12 pecks. The need for this difference in adjustment is not strongly indicated by the above data. These results are quite different from those to be expected from rod-row nursery tests in which a variation in sowing rate may decidedly affect yields through plat competition.

In case of most corn experiments it is recommended that a surplus of seed be sown and the plants thinned in the seedling stage to the desired stand. Especially if single row plats are used this precaution should be supplemented by harvesting only hills containing a full stand and surrounded by a normal stand. Without such precautions, the competition between adjacent rows differing materially in stand for any reason may lead to faulty results and unreliable conclusions. At the Nebraska Station approximately 50 acres of corn plats are annually planted, with hand planters, at a double rate, thinned in the seedling stage to as nearly the desired stand as possible, followed by discarding all hills at harvest which are deficient in number of plants. By these means yields are based on comparable stands, and inherent yielding capacity rather than the effect of stand differences is measured.

In some corn experiments in which there is high variability of seedling vigor, the thinning should be done systematically by position in the hill, in order to retain a strictly representative population. In occasional experiments involving the question of viability and plant deterioration, these full-stand comparisons may be advantageously supplemented by parallel plantings at the normal rate without thinning.

The planting operations of small grain and forage experiments, in which the plats are sown individually, are simplified by preparation of a planting plan which may be followed in the field, and by having the seed samples labeled as to plat numbers and rate of sowing. Preferably all plats are first measured off and designated by temporary consecutively numbered stakes. If the stakes are placed at opposite ends in the center of the first drill swath of each plat, they are a material aid in drilling the seed. They make possible sowing duplicate plats in succession, which is often a very practical procedure. The additional driving from one plat to its duplicates represents less time and labor than cleaning out the drill between all plats. Seed of the succeeding variety may be carried along on the drill and its plats are then sown in reverse order. In such practise the check plats sown in any one day should be restricted to the area sown to the other varieties on the same day. This will insure comparability of varieties with their checks as to time of sowing in the event of rain interference.

Should it not seem possible to sow an entire varietal experiment consecutively without rain interference, it would be preferable to sow one duplication at a time and thereby avoid sowing the varieties at incomparable dates.

The drill should be thoroughly cleaned, between varieties. Such equipment as an air bellows, air pump, or tube through which air is blown is an aid to ridding the drill of seed lodged in corners and in the various feeds.

CARE OF THE GROWING CROP

A great deal need not be said concerning the care of the growing crop in experimental plats. It is obvious that reasonable care should be taken to prevent molestation by livestock or rodents. A generous distribution of poisoned grain along the margins of fields that are to be planted to corn affords protection against loss of stand by ground squirrels. Likewise gophers should be poisoned or trapped when found working in forage crop plats.

In the cultivation of intertilled crops, careful workmanship will reduce the amount of injury to plants. Uniformity of cultivation in all particulars should be striven for.

HARVESTING THE CROP

Careful, thorough work in the harvesting operations is an essential to reliable field experimentation. Before the plats are harvested they should be carefully examined for shortcomings such as may be caused by defective drilling. It is sometimes advisable to measure and discard certain portions of plats where the discrepancy is self-evident. Likewise, where it is an important part of the project to measure comparative hereditary performance in the corn crop, it may be advisable to reject at harvest all hills with missing plants or which are not surrounded by a normal stand. Yields are then based on the actual number of comparable hills harvested. All of this preparatory work is done in advance of husking.

When small grain plats are badly lodged, the grain along their margins may need to be separated and pushed over into the respective plats before cutting. It is a great convenience to have the binder equipped with a binder engine which operates all of the working parts. This facilitates harvesting when the ground is soft following rains, and two horses can draw the machine which simplifies the team work. At the end of the plat, the team is brought to a stand still but the engine continues to operate and clean out the binder preparatory to the next plat. In the absence of an engine, the platform and elevator canvasses should be cranked by hand.

The small grain shocks of adjacent plats should be so spaced that the bundles are not likely to become mixed in case the shocks

are blown down and somewhat scattered. If a twine is tied around the shock, danger of mixing in this manner is greatly reduced.

When birds are numerous, shock covers should be provided. These may be made economically from old burlap feed bags.

In husking corn it is important that all ears which contain any grain whatever are picked. If several men are husking and one is more particular about this than another, it may prove a distinct source of error. If the stalks are lodged or ears have fallen, especially careful work is required to keep separate the crop from the respective plats.

When the corn is husked from the standing stalks rather than from the shock, it is found convenient to husk into a wagon with three compartments on a side if it is desired to obtain a record of individual row yields. Six rows may then be harvested by three huskers at each round of the wagon. Field weights of the ear corn are perferably taken in the field at the time the plats are husked. A small weighing booth, containing properly adjusted platform scales, may be placed in the field for this purpose.

It is considered more reliable to harvest experimental field plats in their entirety than to base yields on mere quadrats or short rows harvested from each of the plats. If the quadrat method is used, not less than 10 and preferably 20 systematically distributed quadrats should be relied upon as closely representative of a plat.

THRESHING THE SMALL GRAIN CROP

Small grain field plats are commonly threshed by the use of some standard make grain separator. It is usually necessary to make some minor modifications in these machines to adapt them for this special work. These changes consist primarily in (1) the removal of the grain elevator, (2) elimination of the self feeder, (3) providing a hinged door at the foot of the tailings elevator for cleaning out between plats, (4) replacing the grain auger with a shaker-trough device, (5) removal of the grain saving auger in the blower, if one exists, (6) equipment with a high pressure air pump and tank to supply air pressure through a hose which may be directed between plats into the separator at points where grain tends to lodge, and (7) cutting several openings, with covers, into the sides of the separator at convenient places for observing the interior and for introducing the air pressure used in cleaning out the separator.

All these modifications assist in obtaining correct yields and they reduce mechanical varietal mixtures when changing from one plat to another.

Varietal mixing may be further reduced by threshing the replicate plats of any one variety in succession and saving the grain from the last one threshed as the seed supply for the following year. In the case of the check plats, only those should be threshed in any one day which are to be compared directly with the other variety plats threshed on the same day in order to insure uniformity.

In no case is it desirable to thresh all check plats in succession, since some systematic condition may arise which reduces the comparability with other varieties. It is important to operate the separator uniformly throughout any one experiment in order to guard against unequal losses of grain. It is always advisable to test the platform scales with a standard weight each time they are moved in order to verify their correct adjustment. Preferably two men should check each other in reading the scales and when only one man is available, he should systematically check his own readings of the scales.

DETERMINING THE YIELDS ON A COMPARABLE BASIS

Small grain from experimental plats is seldom threshed before it has practically reached an air-dry condition. For this reason the yields may commonly be determined from the weights taken at the time of threshing.

In the case of corn, field weights at the time of husking are not considered final. This crop varies with the variety and conditions of growth as to both shelling percentage and moisture content. Yields should therefore be determined on the basis of air-dry shelled corn per acre. There is usually a practical limit to the amount of ear corn that may be stored for this purpose. Representative 50-pound samples taken at the time of husking from each kind of corn or cultural treatment and placed in 2-bushel burlap bags are satisfactory for making moisture and shelling determinations. These tests should not be completed until the corn has become uniformly air dry. Where facilities permit, artificial drying to a moisture-free condition would be advantageous. A small two-hole, motor-driven sheller is effective for shelling these shrinkage samples.

The comparative yields of various forage, silage, and root crops have significance only when they are based upon a uniform moisture content. At the time the forage from the various plats is weighed, representative shrinkage samples which would approximately fill 2-bushel bags should be secured. If sufficient drying facilities are available, the entire sample may be dried. Otherwise, the samples may be greatly reduced in volume by chopping up the forage in a

small feed chopper and re-sampling. These reduced samples, dried moisture-free in a drying oven, serve for calculating comparable yields from the field weights.

As a result of variable winter killing, forage plats sown to such perennial crops as alfalfa and clover may come to vary decidedly in weed content. In order to be significant, comparative yields from such plats must be accompanied by a statement of the percentage of weeds in the crop harvested.

In closing, it may be stated that the various modes of mechanical procedure herein indicated are intended merely as suggestive of the principles involved and may be modified to fit local conditions and other crops not discussed in this paper. Doubtless those engaged in field experimentation are to be congratulated on the increasing support they have received in recognition of the more exacting requirements of modern field technic. Due to the great importance attached to the results of field experiments and the far-reaching effect they may have upon agriculture, it is to be desired that every institution responsible for such work may provide adequate mechanical equipment and other necessary facilities.

4. MATHEMATICS IN THE SERVICE OF AGRONOMY[1]

J. ARTHUR HARRIS[2]

INTRODUCTION

It was as recently as the Washington meeting of 1922 that I had the pleasure of speaking before this Society on a subject very similar to the present.[3] I would not have consented to appear before you at this time were it not for certain definite convictions.

First, I have a very deep conviction as to the importance of agronomy in our present and future national life.

Agronomy might by some be classified among the applied as contrasted with the pure sciences. Certainly the agronomist has a distinctly practical function to fulfill. He must apply the results of research in physics, chemistry, and biology to crop production on such a scale that, through his efforts, these theoretical sciences may have an immediate human significance.

It is the task of the agronomist to make two blades of grass grow where but one grew before, and to make sure that two blades may be grown on the same spot in the future. Thus he has his responsibility for the national prosperity of the present and for the national well-being of the future. It is his task so to increase crop production per acre that vast areas of our national domain may be withdrawn from present cultivation to serve other immediate needs and to be conserved for future agricultural production when the necessity may arise. Thus upon the persistent and successful facing of his task depends not merely the development of our agriculture, but, in some measure, the reestablishment of our forests and of our grazing lands.

Second, I have very firmly fixed convictions concerning the fruitfulness of the wider application of mathematical methods in agronomic research.

Because of the necessarily high complexity of the conditions which surround crop production under practical agriculture, and even on the plats of the experiment station grounds, the agronomist must of necessity work with the statistical method involving relatively large numbers rather than with the stringently experimental method involving highly controlled conditions.

[1]Paper read as part of the symposium on "Field Experiments" at the meeting of the Society held in Chicago, Ill., Nov. 18, 1927. Contribution from the Department of Botany, University of Minnesota, Minneapolis, Minn.

[2]Head of Department.

[3]HARRIS, J. ARTHUR. The service of statistical formulae in the analysis of plat yields. Jour. Amer. Soc. Agron., 18:247–273. 1926.

Since this second conviction will be the main subject of my discussion, I shall not develop it further for the moment.

Third, I have the conviction that with proper refinement of methods of experimentation and of analysis of numerical data, the results of agronomic research may have a value far wider than that indicated by the conventional limits of the term *Agronomy*. If agronomic investigations can be placed on a quantitative basis, with respect to both the technic of experimentation and the analysis of the results of experimentation, material contributions to biology as well as to practical agriculture may be realized. This is a subject which must be developed on another occasion.

THE AGRONOMIST AS ENGINEER AND AS INVESTIGATOR

To this audience it will be a platitude to say that the development of an efficient, productive, and permanent agriculture must depend upon the application of the results of research in the fields of physics, chemistry, and biology to all of the problems of the relationship of the plant to the environment afforded by the length of the growing season, by the physical and chemical properties of the soil in which it is rooted, and of the atmosphere by which it is surrounded, and by the higher and lower plant and animal organisms with which it must compete. Nor is it necessary to reiterate that crop production is an economic as well as a biological phenomenon.

Instead, I should like to stress an idea which seems to me to have received too little consideration. Workers in pure science are wont to think that they deal with *problems*, while workers in the applied sciences deal merely with *application*. I will venture the suggestion that the task of applying the results of all the various kinds of scientific research which pertain to successful crop production is in itself a problem of first-order magnitude. Since crop production is an economic as well as a biological phenomenon, scientific principles will be applied in practise only as they can be made to pay.

The problem of the agrononist is analagous to that of the industrial chemist who must take the principles developed by refined laboratory research, conducted on a small scale, and without much regard to the cost of equipment or materials, make them *work* in *practise*. In his relation to other fields of research the agronomist falls, therefore, in the class which I have elsewhere designated as the "Biological Engineer".[4]

As a biological engineer the agronomist faces a group of problems which are far more difficult than those which confront the civil,

[4]Harris, J. Arthur. The Biological Engineer. Scientific Monthly, 21:581–585. 1925.

hydraulic, mechanical, or electrical engineer. His problem is unusually tangled because of the fact that in crop production all of the variables can not be anticipated or controlled as readily as in other fields of engineering. The assertion is sometimes made that in irrigated regions all of the factors are under the control of the operator, and crop production is not farming, but manufacturing. Those who have had some experience with irrigation agriculture realize that there is a whole group of uncontrollable or difficultly controllable variables which may influence results.

Before the agronomist can recommend the application in practical agriculture of any particular result of laboratory investigation, he must generally test it out experimentally under conditions simulating those under which it is to be applied. Methods which give definite results with plants grown in pyrex glass in the physiological laboratory may not give the same results in the field. Methods which the experiment station can afford to follow in research may not pay dividends when applied on the average farm. The agronomist has, therefore, the task of testing the suggestions which flow from small laboratory or plat experiments in order to determine whether they can be trusted to give valuable results in the hands of those who are not primarily interested in experimentation but must make the farm accounting sheet show a positive sign under the "sales *less* costs" entry.

The agronomist is not, however, limited in his work to the practical application of the results secured by others in the field of the fundamental sciences. In many cases the agronomist cannot find the theoretical solution of his problems expressed in terms of the results of laboratory research. He cannot wait indefinitely until some physicist, chemist, or biologist provides the theory for his application. Furthermore, many of the problems by their very nature cannot be investigated under controlled laboratory conditions.

In such cases he must turn for the time being from the problem of application to the problem of investigation. Since he cannot generalize from the results of laboratory research, he must perforce rely on the results of his own experiments made in the field. He naturally appeals to the method of plat tests.

If the agronomist is to draw conclusions of large economic and social significance from his plat experiments, two things are essential. *First*, they must be wisely planned and accurately executed. *Second*, they must be properly interpreted.

It is my belief that in the interpretation of his results the agronomist not only may but must employ to an increasing extent the biometric method of reasoning.

In my former paper I dealt very concretely with the various kinds of service which the modern biometric methods may render to the analysis of the data of plat yields. On this occasion I shall forego specific illustrations and say more of general principles. In considering these general principles I shall touch only the most elementary, showing how closely in accord with agronomic experience the fundamental statistical conceptions are.

FUNDAMENTAL MATHEMATICAL CONSIDERATIONS

The first task of the mathematician is to define clearly his problem. This will be done here in terms of the purposes, methods, and results of field experimentation.

Whatever may be the specific purpose of a given set of plat cultures, the broad purpose of such tests is to enable the agronomist to provide his constituents with sound generalizations concerning the disease resistance, the quality, the yield, or other valuable properties of agricultural varieties, or concerning the methods of producing them on a commercial scale.

As a basis for his conclusions he has a series of experiments very small in comparison with the total area which may be planted to a given variety or grown according to the cultural technic which he may recommend as the result of his experiments.

The fundamental problem is: How trustworthy are the conclusions drawn from his experiments?

THE TRUSTWORTHINESS OF AGRONOMIC EXPERIMENTS

In order to meet the purposes outlined immediately above, the results of agronomic experiments must be trustworthy. By this I mean that they must, within the limits of all practical requirements, justify the recommendations which the agronomist may base upon them.

Such trustworthiness can not be obtained by refinement of experimental technic and measurements alone, for this is not the kind of reliability that is required. Silage corn can be weighed to tons, hundredweights, pounds, or even to ounces per acre. The yield of grain for two experimental plats representing different dates or rates of seeding, depths of plowing, or other treatment may by the proper expenditure of time and care be so harvested, weighed, and recorded that one may feel assured that the results are correct to a fraction of a gram. But the fact that they are technically correct for the two specific plats in question does not assure the experimenter that his two results are trustworthy *as a basis for generalization*. Everyone who has conducted field trials on an extensive scale, or who has occupied

himself with the analysis of the data of others, has been brought face to face with the hard fact that agricultural experiments can not be repeated with exactly the same results. Conclusions which he would have been glad to draw from the harvest of 1926 are reversed by the yields for 1927, and he is forced to postpone generalizations until the tests of 1928, or even those of many subsequent years, are completed.

Thus it is not sufficient that the experimental results be trustworthy as individual data. They must be *trustworthy as a basis of generalization or as a basis for prediction or as a basis for recommendation.*

This latter kind of trustworthiness is that which the biometrician designates as *significant.* Suppose two sets of plat yields, A and B, be recorded and found to differ by 10 ± 15 pounds. The difference of 10 pounds is trustworthy as an experimental datum, if the technic was correct. The difference does not, however, justify the conclusion that series A and B are *significantly* different by 10 pounds in yield because the difference is of approximately the same amount as its probable error.[5] If it is to be stated as a general and widely applicable conclusion that the difference of 10 pounds is really significant, as a basis for the conclusion that series A and B really differ by this amount, the experiments must be so improved in accuracy or increased in number that the probable error will be reduced to a relatively small fraction of the difference.

THE PROBABLE ERROR AS A CRITERION OF THE VALIDITY OF GENERALIZATIONS DRAWN FROM EXPERIMENTS

The determination and interpretation of the probable error as a criterion of the validity of biometric constants as a basis for generalization presents certain special difficulties in the case of agronomic research.

If a given set of data are to serve as a basis for generalization, the data themselves must be typical of the phenomenon concerning which the generalization is to be drawn. In statistical terminology, the variates measured must be a random sample of the population or universe to which the generalization is to be applied. This means merely that the sample of the population must be taken without bias or prejudice or selection from the whole which it is assumed to represent. An illustration will make this point quite clear. An accurate prediction of the corn, wheat, or cotton yield of a state can not be

[5]When the biometrician states that two results are *significantly different*, he is abbreviating the statement that they are *significantly different in comparison with their probable error.* He implies, and often says, that they *are significantly different in comparison with the probable error of random sampling.*

made by selecting the best or the poorest farms as a basis of estimate. A typical sample, or a random sample, of the farms must be taken. Otherwise, the yields actually measured or critically estimated are not typical of the far larger number of yields which, for lack of time, cannot be measured, and the generalization is worthless. As stated in terms of this illustration, this point may seem so self-evident as not to merit attention. Almost equally obvious considerations are, however, often neglected in the interpretation of probable errors by statistically untrained workers.

In all investigations involving statistical reasoning, it is difficult for the student to be assured that the things which he measures are really typical of the population as a whole. I know of no other field in which the difficulties are so great as in plat test records.

Soil conditions at the experiment station cannot in general be typical of the state at large. Agricultural technic in the research institution should not be that of the farming population as a whole. Furthermore, the difficulties are increased by the fact that some variations between the yields of plats are due to differences in soils from plat to plat, while others are due to variations in conditions of growth from season to season. In short, variation may be due to the influence of factors associated with both space and time.

Suppose a series of yields to be determined on the basis of a number of plats grown during a given year. Experience shows that these will differ among themselves. In so far as these differences are due to diversities in the soil conditions of the different plats they may be said to be due to differentiations in space. But every agronomist of extensive personal experience knows that because of differences in meteorological conditions the crop yields on the same plats may differ widely from year to year. This is variation due todifferentiation in time.

Now a probable error of the difference between two mean yields obtained in one year, representing two varieties or two methods of fertilization, might be quite significant as a basis of generalization for the given year, but not be significant as a basis of generalization for another year, since the crops might conceivably behave quite differently under the climatic or pathological environment of another season.

Clearly the conclusions which the agronomist may draw will be of the greatest value if they are applicable to agricultural conditions as they obtain over a long period of years. Since the results of one year are not necessarily the results of another year, he cannot generalize for a future period of years with confidence unless his experimentation itself covers a period of years.

That wholly reasonable propositions underlie the theory of the probable error as a criterion of the value of a series of experiments as a basis for a generalization will be evident from the consideration of two propositions.

First, the trustworthiness of a generalization will be proportional to the consistency of the experimental results upon which it is based. This is wholly in accord with ordinary common sense and with the common sense that has found expression in the form of mathematical formulae.

Second, the trustworthiness of a generalization is, in some measure, proportional to the number of experiments on which it is based. Stating the results in terms of the probable errors of the constant, we note that the probable error of the mean, for example, is:

$$E_{\bar{x}} = 0.6745 \frac{\sigma_x}{\sqrt{N}}.$$

This shows that the probable error is directly proportional to the variability of x, as measured in terms of its standard deviation, and inversely proportional to the square root of the number of experiments. The value 0.6745 is merely a convention which might be dispensed with were it not for the confusion that might result therefrom.

Now the number of observations is, within limits imposed by time and expense, at the will of the investigator. The standard deviations of the measurements are inherent in the plant materials or in the conditions under which they are grown.

Obviously, the standard deviations of yield on experiment station plats may be quite different from those on commercial areas. In consequence there is grave danger in generalizing for commercial operations from experimental results which differ by only small ratios to their probable errors.

Furthermore, if conditions influencing crop production vary greatly from year to year, the standard deviation of the yields for a series of plat yields grown in one year may be much smaller than that of a series of yields grown over a long period of years. Grave errors might result in the basing of probable errors on the standard deviations of the results of a single year's experimentation.

Finally, the standard deviation is itself a constant with a probable error. If the standard deviation employed in determining the probable error of the mean be based on too few observations to give it a reasonably trustworthy value, the probable error of the mean on which so much reliance is ordinarily placed may be somewhat erroneous.

It will be evident from the foregoing considerations that two methods are available to the investigator who would increase the precision of his results. One is the control of all of the factors which influence variability, with the result that the standard deviation of the given constant will be reduced to its minimum value. This is the method of stringently experimental control. The other is the replication of experiments on a scale sufficiently large that the probable error will be reduced by an increase in $\sqrt{N}$ or $\sqrt{2N}$. The method to be employed must be determined in part by the exigencies of the investigation.

Instead of pursuing this point further, I shall deal briefly with some of the problems of the influence of errors of measurement on the statistical constants.

ERRORS OF MEASUREMENT AND THE PROBABLE ERROR OF EXPERIMENTAL RESULTS

The assumption is sometimes made that because individual measurements are only approximately correct, statistical results of a higher degree of precision cannot be obtained. On the other hand, some appear to think that the accuracy of the statistical constants is practically independent of the errors of the measurements, and that the probable error of the experimental result has no necessary relation to errors of measurement. There is, in other words, a tendency to feel that the probable error of the statistical constants covers all the inaccuracies of measurement. Neither of these extremes is wholly correct.

The cardinal term in the calculation of the probable error is the standard deviation of the given constant. In the case of the probable error of the mean and standard deviation, this is directly dependent on the standard deviation of the original measurements.

Let us consider the relationship between the errors of measurement and the statistical constants and their probable errors based on *N* measurements of plat yield.

Let p be the measured yield of any individual plat and P its true yield. Thus, $e_p = p - P$ is the error of measurement. This error is considered positive when $p > P$ and negative when $p < P$. In experimentation the values of P are unknown and we must depend on the measured value, p.

Remembering that e_p is a value with a sign which must be regarded throughout, we may conveniently write $P = p - e_p$. Then in the relation

$$S(P) = S(p) - S(e_p) \qquad \text{(I)}$$

where S denotes summation for all plats, $S(e_p)$ will become o, if we can assume that the errors of measurement are not systematic,[6] so that they will in the long run be equally distributed above and below the true values in any reasonably large series of measurements Dividing by the number of plats,

$$S(P)/N = S(p)/N = \bar{P} = \bar{p} \ldots\ldots\ldots\ldots (II)$$

Thus errors of measurement, *if not systematic*, will not materially affect the mean value *of a considerable series of yields.*

While in a reasonably large number of plats, the errors of measurement, if not systematic, will have no appreciable influence on the mean, the relation of such errors to the variability is quite different.

Working in the terms of $p = P + e_p$, squaring, and summing for the N plats, we have

$$S(p^2) = S(P^2) + S(e_p^2) + 2S(Pe_p) \ldots\ldots\ldots\ldots (III)$$

It has been shown elsewhere that means, standard deviations, and coefficients of correlation may be readily expressed in terms of these moments and product moments about o as origin.[7] Hence by simple processes which need not be given here, we may rewrite III thus

$$\sigma_p^2 = \sigma_P^2 + \sigma_{e_p}^2 + 2r_{Pe_p}\,\sigma_P\,\sigma_{e_p} \ldots\ldots\ldots\ldots (IV)$$

The last term of the right-hand side of equations III and IV will vanish, since within the working range of any experiment there should be no correlation between a yield and the accuracy with which it is measured and since e_p is either positive or negative in sign. It is clear that the squared standard deviation of the actual measurements is simply the sum of the squared standard deviations of the true values of the variable and of the errors of measurement. Thus the standard deviation will be directly increased by errors of measurement.

Let us consider the results which will flow from the application of this method of reasoning to the comparison of two series of plats planted to two different varieties or subjected to two different cultural technics. Let the true yields of these plats be P and Q, their measured yields be p and q, and the errors of these measurements e_p and e_q.

Since for reasonably large numbers of plats the errors of both means will vanish on summation,

$$\bar{P} - \bar{Q} = \bar{p} - \bar{q}, \ldots\ldots\ldots\ldots (V)$$

[6]If, for example, in a series of corn yields, the grain for certain plats was weighed before being dried to an arbitrarily established normal water content, while that of other plats was brought to a standard water content, systematic errors would be introduced. The present reasoning would not then be valid.

[7]HARRIS, J. ARTHUR. The arithmetic of the product moment method of calculating the coefficient of correlation. Amer. Nat., 44:693–699. 1910.

or the differences between the true means will be sensibly identical with the differences between the means of the actual measurements.

But in the determination of the trustworthiness of the difference between $\bar{P}$ and $\bar{Q}$, we require $\sigma_{(\bar{P}-\bar{Q})}$, and we have only values of p and q from which to work.

For an individual pair of plats taken at random from the two series being compared the difference is

$$p-q=(P+e_p)-(Q+e_q) \qquad \text{(VI)}$$

Squaring and summing for the N pairs

$$S[(p-q)^2]=S[(P+e_p)^2]+S[(Q+e_q)^2]-2S[(P+e_p)(Q+e_q)] \qquad \text{(VII)}$$

The third term of the right-hand side of the equation will vanish, providing that (a) the number of plats is reasonably large, that (b) the errors of measurement are truly random and not systematic for both P and Q, and that (c) the cultures of P and Q are so made that there will be no influence of external factors tending to make the pairs of yields alike.[8] Furthermore, terms involving Pe_p and Qe_q, due to the expansion of $(P+e_p)$, $(Q+e_q)$, will vanish.

This will be more clearly evident by writing VII in full, thus

$$\begin{aligned} S(p-q)^2 &= S\,[(P+e_p)-(Q+e_q)]^2 \\ &= S(P^2)+S(Q^2)+S(e_p{}^2)+S(e_q{}^2)-2S(PQ) \\ &\quad +2S(Pe_p)+2S(Qe_q)-2S(Pe_q)-2S(Qe_p)-2S(e_pe_q) \qquad \text{(VIII)} \end{aligned}$$

With N reasonably large the fifth term on the right-hand side will vanish because by definition our P and Q series are independent. The sixth to the tenth term of the right-hand side will vanish, because there is no relationship between the magnitude of a yield and the error made in measuring it, and certainly no relationship between the yields of a Q plat and the error made in measuring a P plat, or *vice versa*, or between the individual errors made in measuring any two P and Q plats.

Under these reasonable limitations VIII becomes, after algebraical processes,

$$\sigma^2_{(p\text{-}q)} = \sigma_P{}^2+\sigma_Q{}^2+\sigma_{e_p}{}^2+\sigma_{e_q}{}^2 \qquad \text{(IX)}$$

Thus two sets of errors of measurement are included in the determination of the probable error of the differences between two varieties or between two cultured technics. If these errors are relatively large as compared with the actual yields, their contribution to the probable error of the difference may be very material.

The conclusion to be drawn from this result is obvious. If agronomists desire to increase the trustworthiness of their statistical constants

[8]It will be shown later that in many cases condition c is not realized in agricultural experimentation.

as a basis of generalization, they can do so only by reducing the errors of measurement to a minimum and by increasing the number of plat yields measured.

We may now turn to a special phase of the problem of the errors of measurement.

While field heterogeneity was realized in a general way by earlier investigators as a source of error, it was not until a coefficient measuring in quantitative terms the amount of the heterogeneity, that its real importance in agricultural experimentation was fully recognized.

In many series of data it is impossible to differentiate between the errors in yield due to the influence of substratum heterogeneity and those due to other factors. A characteristic of the sources of error inherent in differences in the soil is that they tend to make the yields of neighboring plats alike. Thus if the plats which furnish the measured yields, p and q, be distributed at random with respect to each other, equation IX holds. When, however, the two series of yields, p and q, are determined on plats which are so distributed that p_1 and q_1, p_2 and q_2, p_3 and q_3, . . . p_n and q_n are given in close association, the fifth term, $-2S(PQ)$, of equation VIII, can not be neglected Thus we may derive

$$\sigma^2_{(p-q)} = \sigma_P^2 + \sigma_Q^2 + \sigma_{\epsilon_p}^2 + \sigma_{\epsilon_q}^2 - 2r_{PQ}\,\sigma_P\,\sigma_Q \quad . \quad . \quad . \qquad (X)$$

$$\sigma^2_{(P-Q)} = \sigma_P^2 + \sigma_Q^2 - 2r_{PQ}\,\sigma_P\,\sigma_Q = \sigma^2_{(p-q)} - \sigma_{\epsilon p}^2 - \sigma_{\epsilon q}^2. \qquad (XI)$$

If we can assume that errors of measurement are reduced to such a minimum value that they can be neglected, X becomes

$$\sigma^2_{(p-q)} = \sigma^2_{(P-Q)} = \sigma_P^2 + \sigma_Q^2 - 2r_{PQ}\,\sigma_P\,\sigma_Q \quad \ldots \ldots \ldots (XII)$$

This is the formula which should always be used when errors of measurement are to be neglected but when pairs of plat yields have been grown in association. The probable error of the differences in the means is then

$$E_{(\bar{P}-\bar{Q})} = 0.6745\ \sigma_{(P-Q)} / \sqrt{N} \quad . \quad . \quad \ldots\ldots\ldots \quad . \qquad (XIII).$$

RECAPITULATION

A discussion as brief as the foregoing scarcely merits a summary. I have made no attempt to outline in full the various services which mathematics, particularly that field of mathematics which is associated with the name of Karl Pearson and is sometimes called the modern higher statistics, may render in the analyses of the data of agronomic experimentation. A rather full review of some of the accomplishments of these methods was given in a former address before this Society.

On the present occasion I have sought to emphasize certain of the simpler fundamental principles involved in the application of biometric methods to agronomic data.

The necessity for the use of biometric methods rests in the fact that because of the multiplicity of factors which surround field experiments they cannot be subject to the same exactness of control as those made in the laboratory.

In emphasizing the application of statistical methods to large masses of data, I have not in any way counseled carelessness of experimentation. The data of agronomic investigation must be made as trustworthy as is possible. Some of the simpler relations between errors of measurement and the statistical constants have been indicated.

The value of refinement of both experimentation and interpretation inheres in the far-reaching economic importance of agricultural experimentation and in the possibility of making such research of broader biological value.

5. APPLICATION OF PLAT RESULTS TO AGRICULTURAL PRACTISE[1]

E. L. WORTHEN[2]

The farmer thinks to a large extent in terms of operations. He is primarily concerned with the "what" rather than the "why." Experimental results affect him only in so far as they are sufficiently conclusive to justify a change in his practises. His conservatism in making such changes has often prevented mistakes being made. While willing to modify methods, past experience justifies his following old practises until, through experiments, a change is very definitely shown to be desirable.

There has been a material change the last 25 years in the attitude of the farmer towards agricultural colleges and experiment stations. Experience has strengthened his confidence in the recommendations of agronomists and other agricultural workers. The results of field plat experiments have been of great value in giving the agronomist justification for advising definite soil- and crop-management practises. In fact, by means of plat experiments, results secured through research conducted in the laboratory or greenhouse are checked under field conditions and their application to practical crop production more definitely ascertained. Furthermore, data secured from the field carry more weight with the farmer than do those coming directly from the research laboratory. As a result they supply the extension agronomist with valuable teaching material.

In the application of plat results to agricultural practise the agronomist should consider three factors, *viz.*, (1) the practical interpretation of results, (2) the publication of results, and (3) the utilization of results in extension teaching.

PRACTICAL INTERPRETATION OF RESULTS

Agronomists have given much attention the last decade to the mathematical measurement of error in plat results. They have attempted to determine whether or not such results are significant. The various factors influencing yields have been considered, and conclusions have been drawn less often from results that are within experimental error.

[1]Paper read as part of the symposium on "Field Experiments" at the meeting of the Society held in Chicago, Ill., Nov. 18, 1927. Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y.

[2]Extension Professor in Soil Technology.

In the interpretation of results from the standpoint of their application to agricultural practise the agronomist is confronted with difficulties which have not as yet been evaluated mathematically. Results may clearly be significant and still not sufficiently conclusive to justify their incorporation in the practises of the farmer. Judgment rather than mathematics must be relied on in determining the significance of results from the standpoint of agricultural practise. It is hardly necessary to draw attention to numerous disagreements which have arisen between agronomists in the practical interpretation or application of results from some particular plat experiment.

In evaluating results from the standpoint of their influence on agricultural practise, the less exacting and often less efficient practises of the farmer should be considered. The effectiveness of a change in practise is more or less dependent on the efficiency of the soil management and cropping practises followed. Results may justify a modification in general practise without being applicable in a particular case until other practises have been changed.

For example, assume that plat results justified the application of 2,000 pounds of a particular fertilizer for potatoes. Before this rate of application could be justified good seed must be used, adequate precaution taken to control disease or insect injury, and good soil cultural practises established. Obviously, the advisability of adopting the experimental results in this case might necessitate changes in other cultural practises.

Consideration must also be given to financial returns in the practical application of results. They must be economically sound to be justified. Their acceptance requires in most cases some additional outlay on the part of the farmer. He must have assurance that the expenditure is justified. Not infrequently on account of limited funds it is a question of his choosing between several desirable changes in practise. Consequently, the relative importance of the possible changes must be ascertained. This necessitates the financial interpretation of results by agronomists or by others familiar with the details of the experiment.

PUBLICATION OF RESULTS

From the farmer's viewpoint results in themselves are of little value. He has neither time nor inclination to interpret them himself. They must be presented in a simple and practical way if they are to influence his practises. This requires on the part of agronomists (1) a definite and practical interpretation of results, and (2) their application to agricultural practise by means of publications which are of a more or less popular nature.

Frequently agronomists, hesitating to interpret the results of their own experiments, publish them, leaving to others their interpretation and their application to agriculture. Such publication of results may be justified from the standpoint of making them available to other agronomists; but results which are insufficiently conclusive to justify interpretation from the standpoint of their adaptation to practical problems should not be published in popular bulletins. However, when results are sufficiently conclusive to influence farming practises, they should by all means be published in a form easily comprehended by the average farmer. Interpreting results in a language easily understood should in no way lower the dignity of an agronomist nor the institution which he represents.

UTILIZATION OF RESULTS IN EXTENSION TEACHING

With the development during the last decade of organized extension work in agronomy, there has grown up a new or at least a better organized means of carrying agronomic teaching direct to the farmer. Extension agronomists have during this time developed rather definite soil and crop programs for the various states. These programs are based to no small extent on information secured from plat experiments. To be effective they must include very specific soil- and crop-management practises. The term "salesmanship" has at times been applied to extension teaching and "high pressure" methods of producing results advocated. Even extension agronomists are on the whole conservative, but their teaching methods must have in them a certain popular appeal though they need not go to the extreme sometimes advocated.

Extension agronomy programs must be built on well-established information. They should emphasize definite soil- and crop-management practises. To be effective emphasis should be placed on what to do and when and how to do it rather than why. While necessarily definite in character, such programs should be sufficiently elastic to permit of proper adjustment due to changing economic conditions and to new information furnished by plat experiments or other lines of investigation.

It would seem that as a result of the development of extension teaching in agronomy there has come about a change in organization and in the program of work which influences the application of experimental results to farm practise. These results must now be analyzed not only from the standpoint of their being significant and substantiating other results or, in fact, adding to our stock of agronomic information, but, also from the standpoint of their relation

to the agronomy extension program. If sufficiently conclusive to justify a change in this program, such a change should be made, resulting in the more rapid and universal acceptance of the information through changed practises by the farmer.

Briefly, then, the practical application of experimental results necessitates, first, their evaluation in relation to soil- and crop-management practises; second, their publication in a more or less popular form; and, third, their incorporation in the agronomy extension program.

TRANSFORMATION OF NITROGEN IN RICE SOIL[1]

George Janssen and W. H. Metzger[2]

INTRODUCTION

The changes which nitrogen compounds undergo in soils which are adapted to most farm crops have been rather exhaustively studied. It has been fairly conclusively established that most agricultural plants, with the exception of legumes, obtain the nitrogen required for growth from the soil in the form of nitrates. Some evidence has been presented showing that plants may, and perhaps often do, take up some nitrogen as ammonia. It has also been demonstrated that plants can use nitrogen in the form of soluble amino compounds.

The assimilation of nitrogen by rice has received less attention than in the case of dry land plants due, no doubt, to the fact that the rice crop is not widely adapted in this country, and to the further fact that nitrogen studies in submerged soils offer a difficult problem. Such work as has been doen along this line has led to the general belief that rice plants assimilate nitrogen as ammonia much more readily than as nitrate, and that ammonium salts are superior to nitrate salts as nitrogenous fertilizers for rice soils.

The need for more experimental evidence on the problem of nitrogen transformation in submerged soils led the writers to undertake the work reported here. The experiment was designed to give some evidence on (a) the extent of assimilation of nitrates and of ammonia by the plant, (b) the relative value of green manure, sodium nitrate, and ammonium sulfate as fertilizing material for rice soil, and (c) the changes which nitrogen in these three carriers undergoes in such soil.

PLAN OF EXPERIMENT

The present investigation was limited to pot culture in the greenhouse. In this experiment it was planned to maintain an environment favorable to the plant. Soil classified as Clarksville silt loam was taken from the University farm and used in this experiment. Rice had not been grown on this soil before. Corn had been grown on the land the previous year, and the nitrate and organic matter content of the soil was low. This soil was supplemented with nitro-

[1]Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Ark. Published with the approval of the Dean of the College of Agriculture as Research Paper No. 85, Journal Series, University of Arkansas. Received for publication February 14, 1928.

[2]Assistant Agronomists.

genous fertilizers or green manure as desired. Four-gallon stone jars were used. Fifteen kilograms of soil were used in each jar. In order to study better the assimilation of nitrogen by the plant, one-half of the jars were cropped, the remainder being left uncropped.

From the standpoint of interest and also as a means of comparison, one-half of the cropped, as well as the uncropped jars, was left unflooded. Three treatments were compared with the checks, namely, green manure (soybeans), sodium nitrate, and ammonium sulfate. The green manure was added at the rate of 12 tons per acre. Soybeans (with the pods well formed) were cut into 1 to 1 1/2 inch segments and mixed thoroughly with the soil. Duplicate jars were used in all instances. The sodium nitrate was added at the rate of 250 pounds per acre and ammonium sulfate proportionally. Eight jars were used for each treatment, including the checks. Thus, for the green manure series, eight jars were treated, four flooded and four unflooded. Two in each case were cropped and two left uncropped. The check jars, as well as the sodium nitrate and ammonium sulfate jars, were treated in like manner. All jars which were flooded were submerged at the time the fertilizer and green manure was applied. Honduras rice was germinated in silica sand and, when the seedlings were 3 inches high, transplanted to the various jars. It should be stated that the rice seedlings in the green manure treated jars which were flooded from the beginning of the experiment had to be replanted four times, each time failing to obtain a stand. Finally, a jar in which the green manure had been allowed to undergo decomposition for ten days was flooded and planted to seedling rice. When this method was used rice plants developed normally.

Approximately 14 plants were planted in each jar and later these were thinned to 12 plants per jar. These were then allowed to grow until the completion of the experiment. For the first five weeks samples of the soil were taken from each jar twice each week. Analyses were made for nitrates, nitrites, and ammonia. Total nitrogen was also determined on representative samples of each series at various intervals.

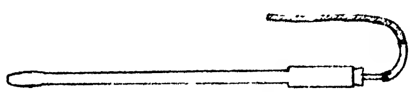

FIG. 1.—Soil sampling device.

In order to obtain a representative sample of soil from each jar, a sampling device was prepared as represented in Fig. 1. It consisted of an ordinary soil sampling tube at the upper end of which was inserted a rubber stopper. A glass tube was introduced through the stopper and this was connected to a rubber tube. Thus, to take a sample of soil from the submerged jar, it was only necessary to insert

the tube into the soil, apply suction to the rubber tube and maintain the created partial vacuum by pinching the tubing and at the same time withdrawing the sampler. In so doing a column of soil equal to the depth of the soil in the jar was removed with the sampler. Two or three of these columns were taken at each sampling. Excess water was drained back into the jar. In the case of dry soils a 1-inch soil auger was used for taking samples. All soil, after sampling, was taken to the laboratory, mixed thoroughly, and analysis made as previously mentioned.

Fifty grams of the dry soil and 60 grams of the soil from the flooded jars were analysed. Nitrates were determined according to the phenol-disulfonic acid method, nitrites with the Greiss colorimetric method, and ammonia by Nesslerization. The colorimeter or Nessler tubes were used to make all readings. A pinch of calcium hydroxide was used as a flocculent for the soil. In the beginning of the experiment, in order to increase the rate of settling and also to facilitate the ease of filtering, about 0.3 gram of aluminum sulfate was added to the soil suspension. It was found that this interfered with the ammonia readings. Calcium hydroxide was then finally the only flocculent used. Readings of the ammonia were made immediately after filtering. If the solutions were allowed to stand after filtering a film of $CaCO_3$ formed over the surface and this interfered with the colorimetric readings. Total nitrogen was determined by the Khel-dahl method modified to include the nitrogen as nitrates.

After a period of five weeks the soil sampling and soil analyses were limited to once each week. It was found that these periodic samplings were sufficient to enable the writers to trace the nitrogen changes in the soil.

EXPERIMENTAL RESULTS

NITRITES

It has been shown by Warington (15),[3] and by a number of other investigators in more recent work, that nitrates are reduced in a soil saturated with water. Furthermore, it is well known that nitrite, one of the products of reduction, is toxic to plants in relatively low concentration. Kelley (7) observed such reduction and obtained concentrations of nitrite as great as 2 p. p. m. He found concentrations of 5 or more p. p. m. to interfere very seriously with growth of rice plants. This work, however, was done in sand cultures and with soil cultures in Erlenmeyer flasks and does not establish a probability that nitrites are likely to be a serious detrimental factor in rice fields, even though fertilized with nitrates.

[3]Reference by number is to "Literature Cited," p. 475.

Immediately after the jars were flooded in this experiment reduction of nitrates seems to have begun. The first sampling, which was done on November 7 two days after the jars were flooded, showed nitrites present in all the jars. The highest concentrations were found in those jars to which nitrate of soda had been added. Even here, however, the highest concentration was only 0.25 p. p. m. At no time later in the experiment did any of the soils show a concentration as high as that of the above and, when the samples were taken January 2, no more than a trace of nitrites appeared in any of the jars of the experiment. Subsequent analyses showed similar results.

The data from the nitrite determinations are shown in Table 1. In this table and those which follow, the soil treatments corresponding to the various jar numbers are as follows: Jars 226, 227, 228, 229 green manure, flooded, not cropped; 230 and 233 green manure, not flooded, cropped; 231 green manure, flooded, cropped; 232 green manure, not flooded, not cropped; 234 and 235 sodium nitrate, flooded, cropped; 236 and 237 sodium nitrate, flooded, not cropped; 238 and 239 sodium nitrate, not flooded, cropped; 240 and 241 sodium nitrate, not flooded, not cropped; 242 and 243 ammonium sulfate, flooded, cropped; 244 and 245 ammonium sulfate, flooded, not cropped; 246 and 247 ammonium sulfate, not flooded, cropped; 248 and 249 ammonium sulfate, not flooded, not cropped; 250 and 251 no treatment, flooded, cropped; 252 and 253 no treatment, flooded, not cropped; 254 and 255 no treatment, not flooded, cropped; and 256 and 257 no treatment, not flooded, not cropped.

AMMONIA

It is now rather universally understood in the field of rice nutrition that ammonia coupled with some anion forms a better source of nitrogen for assimilation by the rice plant than sodium nitrate. This fact was derived by Stubbs (13) and confirmed by others (9, 5, 8, 7, 14, 10). It was not the aim of the writers to substantiate these results, but rather to make a comparative study of the rate and amount of ammonification of soils receiving green manures, sodium nitrate, and ammonium sulfate, on submerged, non-submerged, cropped, and uncropped rice soils. It was also desired to know the rate and time at which the ammonia disappeared in flooded as well as dry soils.

The data of the ammonia changes in cropped and uncropped submerged and unsubmerged soils over a period of two months from the time the rice plants were planted to the time they had reached a

Jar No.	Nov. 7	Nov. 10	Nov. 14	Nov. 18	Nov. 21	Nov. 25	Nov. 28	Dec. 1	Dec. 5	Dec. 12	Dec. 19	Dec. 27	Jan. 2	Jan. 9	Jan
226	0.013	t[a]	t	t	t	t	t	0	0	t	0.028	0	t	t	t
227	0.013	t	t	t	t	t	t	0	0	t	0.026	0	t	t	t
228	0.028	t	t	t	t	t	t	0	0	t	0	0	t	t	t
229	0.032	t	t	t	t	t	t	0	0	t	0	0	t	t	t
230	0.005	t	t	t	t	t	0.029	0.022	0	t	0	t	t	t	t
231	0.005	t	t	t	t	t	0.060	0.024	0	t	0	t	t	t	t
232	0.005	t	t	t	t	0.060	0.017	0.030	0	t	0	t	t	t	t
233	0.005	t	t	t	0.04	0.250	0.017	0.031	0	t	0	t	t	t	t
234	0.064	0.033	0.048	0.038	t	0.060	0.037	0.060	0.059	0.095	0.021	0.031	t	t	t
235	0.103	0.047	0.064	0.056	t	0.060	0.034	0.060	0.059	0.056	0.020	0.024	t	t	t
236	0.064	0.029	0.064	0.036	t	0.060	0.017	0.059	0.049	0.056	0.021	0.024	t	t	t
237	0.065	0.033	0.066	0.035	t	0.065	0.018	0.060	0.029	0.059	0.022	0.024	t	t	t
238	0.006	t	t	t	t	t	0.017	0.030	0	0.041	0.017	0.017	t	t	t
239	0.006	t	t	t	t	t	0.017	0.030	0	0.042	0.016	0.017	t	t	t
240	0.006	t	t	t	t	t	0.017	0.031	0	0.023	0.017	0.017	t	t	t
241	0.006	t	t	t	t	t	0.017	0.031	0	0.024	0.020	0.018	t	t	t
242	0.020	t	t	t	t	0.025	0.038	0.034	0.048	0.036	0.024	0.036	t	t	t
243	0.019	t	t	t	t	0.058	0.039	0.034	0.059	0.035	0.024	0.038	t	t	t
244	0.030	t	t	t	t	0.052	0.059	0.034	0.028	0.031	0.024	0	t	t	t
245	0.018	t	t	t	t	0.050	0.032	0.034	0.035	0.030	0.018	0.043	t	t	t
246	0.005	t	t	t	t	t	0.012	0.025	0.027	0.026	0.020	0.029	t	t	t
247	0.006	t	t	t	t	t	0.012	0.024	0.028	0.025	0.021	0.029	t	t	t
248	0.006	t	t	t	t	t	0.018	0.025	0.034	0.026	0.023	0.028	t	t	t
249	0.006	t	t	t	t	t	0.018	0.023	0.018	0.024	0.022	0.028	t	t	t
250	0.006	t	t	t	t	0.031	t	0.022	t	t	t	t	t	t	t
251	0.006	t	t	t	t	0.032	t	0.023	0	t	t	t	t	t	t
252	0.006	t	t	t	t	0.031	t	0.022	0	t	t	t	t	t	t
253	0.006	t	t	t	t	0.031	t	0.023	0	t	t	t	t	t	t
254	0.005	t	t	t	t	t	0.012	t	0	t	t	t	t	t	t
255	—	—	t	t	t	t	0.012	t	0	t	t	t	t	t	t
256	—	—	—	t	t	t	0.011	t	0	t	t	t	t	t	t
257	—	—	—	t	t	t	0.011	t	0	t	t	t	t	t	t

[a] t = trace, i. e., less than 0.0055 p.p.m.

height of 24 inches are given in Table 2. Fig. 2 shows results for soils which received ammonium sulfate treatment with the nitrogen applied equivalent to the nitrogen in a 250-pound application of sodium nitrate. From the table it will be noted that the ammonia analyses from time to time vary greatly. However, in all instances soil from duplicate jars was analysed. To obtain the results given in Fig. 2, the average of two analyses was taken. This means the average results of the analyses of soil from four jars. When the data were averaged in this manner the curves were smoothed to a large

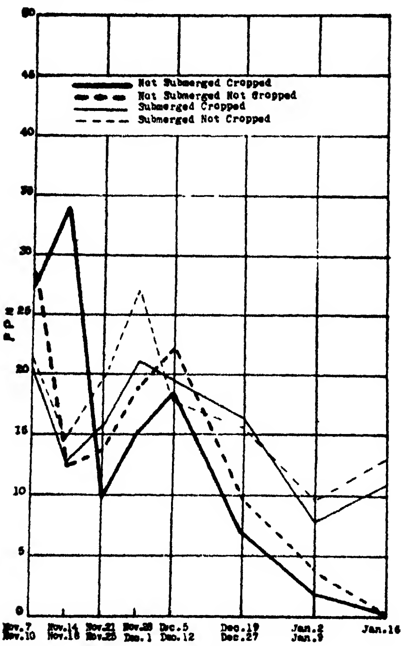

FIG. 2.—Changes of ammonia in soils treated with ammonium sulfate.

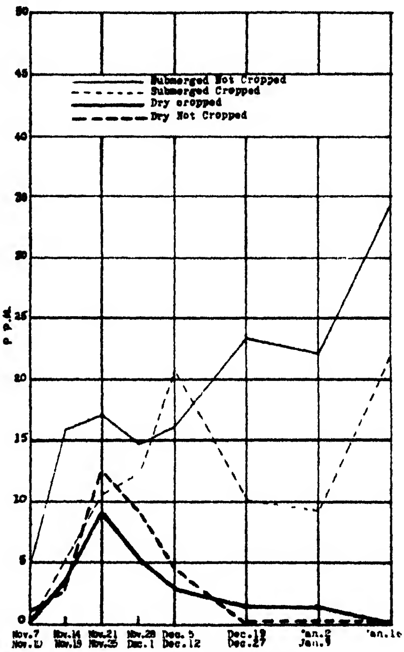

FIG. 3.—Changes of ammonia in green-manured soils.

extent, though considerable fluctuation still existed. This will, in part, be accounted for in the discussion. Fig. 2 shows in general a constant decline of ammonia in the soil of all jars, the greatest decline and most rapid loss being found in unsubmerged soil, ranging from about 25 p. p. m. at the beginning (November 7) of the experiment to a trace on January 16, when analyses were discontinued. Comparing this with the flooded jars, approximately 21 p. p. m. were found on November 7 to 10, diminishing to about 10 p. p. m. on January 2. These results are in harmony with the findings of Kelley (7) and Panganiban (10). By comparing the uncropped dry as well as submerged soils it is evident that the greatest reduction of ammonia

is due to biological or chemical action rather than assimilation of nitrogen by the plant. The plant is responsible, however, for reducing the ammonia through its assimilation as shown in the difference between figures obtained from analyses of the cropped and uncropped soil. These data indicate that Panganiban might have erred in assuming that the decrease in ammonia was entirely due to assimilation by the rice plants.

The data on ammonia changes where green manure was applied to the soil at the rate of 12 tons per acre are given in Fig. 3. As will be noted, the ammonia in the flooded soil increased from 0 and 4 p. p. m. to 22 p. p. m. for the cropped soil and 35 p. p. m. for the uncropped soil.

It is interesting to note the immediate increase in ammonia produced in the uncropped soil. The cropped submerged jar was not flooded until November 26 and it will be noted from Fig. 3 that the ammonia increased from 10 p. p. m. to 21 p. p. m. within two weeks time. After this it decreased, no doubt due partially to the fact that some of the ammonia was being assimilated by the plants. The last analysis includes only one determination and hence may be too high for the proper value. It should be noted that immediately after flooding ammonification proceeds rapidly, and in this experiment ammonia continued to increase in uncropped soils for at least two months. The ammonia in the unflooded soils increased from 0 on November 7 to 12.5 p. p. m. on November 21 to 25, or three weeks after beginning the experiment, then there was a gradual decline until January 16 when no more ammonia was present in the cropped soil. Little or no ammonia was measured in the soil of jars which received sodium nitrate or in soil which received no treatment, especially where the soil remained unflooded. Hence, these treatments need no discussion.

The fact has already been brought out that the rice plant can better assimilate nitrogen from ammonium compounds than from nitrogen. The physiological basis for this fact is not understood. The writers have not attempted to make this a part of their study. Since the rice plant prefers to assimilate nitrogen from ammonia to carry on its metabolic processes, the problem is to maintain ammonia in the soil. It is well understood that the ammonifying power of soils, the promptness with which ammonification takes place, varies for different soils as well as the same soil under varying temperatures and moisture conditions.

Coleman (2) found no ammonia produced at 6° to 8°C and that below 20°C the production of ammonia was marked. The optimum temperature was found to be 30°C and declined at 38°C. According

TABLE 2.—*Nitrogen as ammonia in p.p.m. of oven-dry soil on variously treated rice soils.*

Jar No.	Nov. 7	Nov. 10	Nov. 14	Nov. 18	Nov. 21	Nov. 25	Nov. 28	Dec. 1	Dec. 5	Dec. 12	Dec. 19	Dec. 27	Jan. 2	Jan. 9	Jan. 16
226	3.3	5.2	9.0	30.5	20.6	7.3	13.8	11.8	16.0	13.9	9.4	33.9	29.0	24.8	35.2
227	3.2	6.9	9.0	24.9	20.8	8.8	15.2	11.2	21.5	13.5	12.1	35.3	26.7	16.4	32.8
228	3.5	4.4	7.5	23.6	28.5	9.1	9.9	19.5	22.6	13.7	13.7	31.2	21.6	11.7	38.0
229	3.2	5.1	7.3	32.1	22.5	9.6	11.2	24.0	14.9	19.0	14.1	37.0	26.4	27.3	32.2
230	t[a]	t	3.1	3.9	4.4	t	8.3	6.0	3.1	t	t	t	o	2.3	t
231	t	t	3.2	9.0	14.9	6.3	12.8	12.1	16.8	25.0	9.9	10.7	8.6	10.3	22.2
232	t	1.7	t	6.5	13.4	11.8	4.0	13.4	t	8.5	t	t	o	t	t
233	t	t	t	8.9	13.2	18.7	t	7.2	t	8.5	3.0	3.1	3.9	t	t
234	t	2.4	t	3.3	4.9	t	t	o	t	t	t	t	5.1	t	t
235	t	5.2	t	5.0	4.9	t	t	o	t	t	t	t	3.5	t	t
236	t	4.1	t	t	3.5	t	t	5.0	t	t	t	t	4.9	6.1	9.6
237	t	2.6	t	6.5	4.9	t	t	12.6	t	t	t	t	6.3	4.3	7.0
238	t	t	t	t	t	t	t	7.8	t	t	t	t	o	t	t
239	3.0	t	t	3.5	t	t	t	12.1	t	t	t	t	o	t	t
240	t	t	t	t	t	t	t	o	t	t	t	t	o	t	t
241	3.1	t	t	3.9	t	t	t	o	t	t	t	t	o	t	t
242	32.9	15.4	9.2	13.9	20.7	10.1	14.5	25.5	19.8	16.7	17.2	19.2	9.3	7.2	9.0
243	12.8	21.6	8.1	20.0	19.5	13.1	17.0	27.2	24.9	16.5	9.1	19.8	8.4	6.0	12.7
244	31.0	15.6	8.9	27.9	16.4	18.2	18.3	39.5	19.4	17.4	9.2	22.6	15.8	13.0	17.8
245	18.8	20.8	10.5	11.7	35.8	7.6	11.1	39.5	21.1	13.4	7.9	22.6	13.3	7.6	17.9
246	11.6	38.1	13.6	33.6	10.3	9.3	14.5	17.0	15.4	17.6	1.9	7.8	5.1	2.9	t
247	30.5	29.4	12.5	76.8	8.3	9.3	13.0	15.6	15.2	26.0	11.2	6.9	o	t	t
248	30.9	27.3	9.9	12.3	11.1	13.2	12.0	12.4	15.3	17.6	12.1	3.8	2.1	4.8	t
249	30.8	27.1	9.9	17.7	13.9	14.1	26.4	25.0	19.0	37.9	8.7	13.4	4.9	2.8	t
250	t	2.1	t	4.4	8.4	3.6	2.4	t	t	3.8	t	t	3.8	2.6	3.7
251	t	2.8	t	4.5	7.3	t	3.1	t	t	4.0	t	t	4.6	2.4	4.8
252	t	4.1	t	3.1	6.2	t	1.7	t	t	3.8	t	t	6.6	4.4	9.0
253	t	2.5	t	4.3	6.4	t	1.9	t	t	8.8	t	t	8.6	4.0	8.5
254	t	1.8	t	3.9	t	t	o	t	t	11.0	t	t	o	t	t
255	t	t	t	5.3	t	t	o	t	t	2.0	1.8	t	o	t	t
256	t	t	t	3.3	t	t	o	o	t	7.1	t	t	o	t	t
257	t	t	t	6.0	t	t	o	o	t	10.1	t	t	o	t	t

[a]t = trace, i. e., less than 1 p.p.m.

to this author moisture also plays an important rôle. He found that, "Some fungi produced ammonia in soil with 7% of moisture, but that most species displayed greatest activity at 14% to saturation, at which point ammonification declined sharply."

Flooded rice soils represent an anaerobic condition. Organic matter therefore undergoes putrifaction rather than decomposition. Pieters (11) cites the statement of Jeannert that through the exclusion of air "decomposition is considerably less rapid and complete decomposition requires, with the exclusion of air, a period of time six times as long." This would indicate that the liberation of ammonia from green manure under submerged conditions would be greatly retarded. Panganiban (10) found that paddies during submerged conditions decreased in ammonia from 66.7 p. p. m. when the soil was lying fallow to a trace during the time the soils were planted and submerged. He quoted Kelley's (7) results as being in close harmony with his own. However, in Kelley's work it was stated that there was some decomposition as evidenced by the evolution of CO_2 and yet little ammonia was produced. Panganiban explained the disappearance of ammonia on the suggestion that it was assimilated by the rice plants.

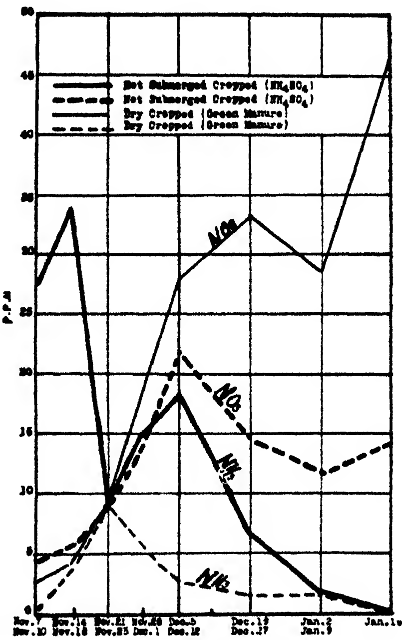

FIG. 4.—Changes of nitrate and ammonia in soils treated with green manure and ammonium sulfate.

The results in Fig. 2 on the ammonia in cropped, uncropped, and flooded soils treated with ammonium sulfate at the rate of 200 pounds per acre are similar to the ammonification results obtained by Kelley (7) in his rice soils. However, he obtained a faster rate of ammonification in soils under aerobic than under anaerobic conditions.

The disappearance of ammonia from rice soils has been a question of controversy. In the work reported here it is evident that much of the ammonia in the dry soils has been changed over to nitrates as revealed in Fig. 4, drawn from data for soils treated with green manure, and Figs. 2 and 6, for soils treated with ammonium sulfate.

It was shown by Panganiban (10) that amino nitrogen was formed in submerged soils. It has also been shown by other workers that some of the higher plants can assimilate amino forms of nitrogen. The writers found that the rice plant was capable of assimilating some of the amino acids in culture solution. Potter and Snyder (12) have also found that under certain conditions amino nitrogen may be taken up by the plant. Fig. 3, showing ammonia changes as the result of decomposition of organic matter in submerged soils, is interesting since there is a steady increase from 4 p. p. m. to 35 p. p. m. over a period of two months.

As previously noted, however, Coleman (2) found temperature to be an important factor in determining the rate of ammonification. The air temperature above the soil in this experiment was kept near 80°F which should be optimum according to the above investigator. Comparing the ammonification in dry and submerged soil, it will be noted from Fig. 3 that there was a greater rate for the first two weeks in the submerged soil than in the unsubmerged soil. However, it may have been that the ammonia was changed to nitrates immediately, and therefore, was not measured. This is suggested by the data given in Fig. 4. After the first two weeks the ammonia decreased until on January 16 it was not present in quantity sufficient to be measured.

NITRATES

It seems fairly well established that nitrogen in the form of nitrates does not perform a major rôle in the nutrition of rice plants. This, it has been shown, is true for two rather well-defined reasons, *viz.*, (a) nitrates are reduced in a submerged soil and are nearly completely removed, and (b) the rice plant clearly prefers ammonia to nitrates as a source of nitrogen.

In order to determine the rate of reduction of nitrates and to measure the extent of utilization of nitrogen in this form, determinations of nitrates were made for all jars at each sampling.

The results of the nitrate determinations are listed in Table 3. In all cases a rapid disappearance of nitrates occurred in the submerged soil. This was undoubtedly due to reduction as a result of biological activities in the soil. It is of interest to note, however, that at no time in the duration of the experiment did nitrates entirely disappear from the submerged soil. All such samples continued to show a trace of nitrates. Concentrations of less than 1 p. p. m. of nitrogen as nitrate are reported as traces. Considering the statement of Copeland (4) that rice "requires both nitrates and derivatives of ammonia," such very small amounts of nitrates may be of some importance.

A great deal of fluctuation will be noted in the nitrate content of the various jars, both as to agreement of duplicate jars and as to the data for any one jar in successive samplings. The probable reasons for this will be discussed later.

The data for nitrate changes of soil treated with sodium nitrate and ammonium sulfate are shown in graphic form in Figs. 5 and 6. In order to eliminate some of the variations in Table 3, the data have been grouped in the same manner as for ammonia before plotting

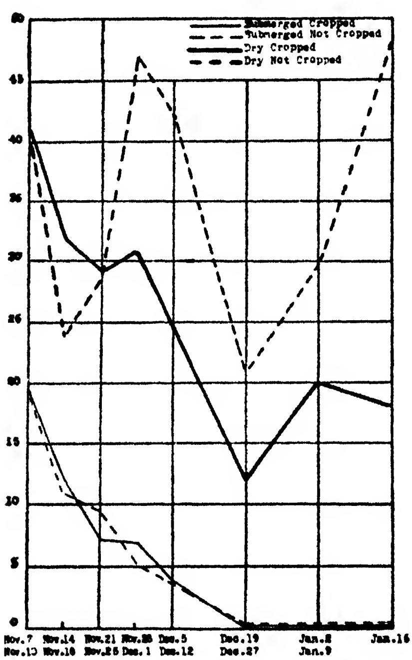

FIG. 5.—Changes of nitrate in soils treated with sodium nitrate.

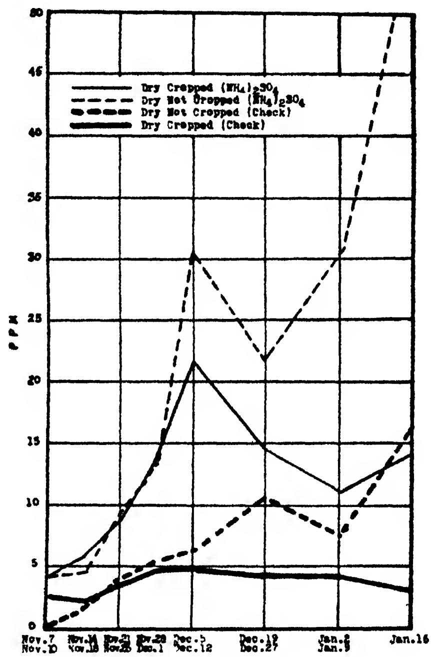

FIG. 6.—Changes of nitrate in checks and soils treated with ammonium sulfate.

the curves. In three cases the results obtained were obviously at fault and, therefore, were not considered in plotting the curves. These three cases were as follows: Jar 239, Dec. 1 and 5, 82.6 and 87.2, respectively; and jar 249, Dec. 12, 63.9.

By a study of Table 3, and more particularly, Figs. 5 and 6, it will be noted that the plants undoubtedly drew upon the nitrates of the soil in the non-submerged series. Especially is this noticeable in Fig. 6 where the check jars, cropped and not flooded, are compared to the uncropped, non-submerged checks. In the later samplings the accumulation of nitrates in the planted checks had been stopped because of the use of nitrates by the plants. This tendency was ex-

TABLE 3.—*Nitrogen as nitrates in p.p.m. of oven-dry soil on variously treated rice soils.*

Jar No.	Nov. 7	Nov. 10	Nov. 14	Nov. 18	Nov. 21	Nov. 25	Nov. 28	Dec. 1	Dec. 5	Dec. 12	Dec. 19	Dec. 27	Jan. 2	Jan. 9	Jan. 16
226	t[a]	t	t	t	t	t	t	t	t	t	t	t	t	t	t
227	1.7	t	t	t	t	t	t	t	t	t	t	t	t	t	t
228	1.9	t	t	t	t	t	t	t	t	t	t	t	t	t	t
229	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t
230	3.6	2.1	3.3	4.8	4.4	6.5	19.0	15.3	15.2	23.7	22.0	23.9	8.4	52.1	50.4
231	3.5	1.7	2.9	4.4	4.0	11.3	1.9	t	t	t	t	t	t	t	t
232	3.4	2.3	2.9	5.1	4.8	11.8	18.6	17.4	12.7	30.2	68.8	29.6	25.6	81.2	38.3
233	3.3	2.4	3.0	5.1	4.4	22.8	22.1	18.1	22 9	50.4	39.4	47.1	26.5	27.3	42.2
234	18.2	18.1	18.4	6.8	6.1	6.9	10.2	7.5	5.9	3.0	t	t	t	t	t
235	22.7	19.5	14.3	10.4	10.7	5.9	5.0	4.6	3.3	2.8	t	t	t	t	t
236	19.2	19.4	18.7	5.3	5.8	10.4	5.7	4.9	6.0	2.7	t	t	t	t	t
237	21.7	18.6	14.3	7.0	6.7	6.5	5.9	4.8	3.3	2.9	t	t	t	t	t
238	40.6	51.6	46.4	27.0	22.4	37.9	46.8	32.2	20.0	21.0	15.6	8.1	27.8	9.1	24.8
239	26.4	48.6	29.5	25.9	22.3	33.5	23.2	82.6	87.2	33.5	13.8	8.2	14.9	29.4	11.4
240	32.6	42.8	33.4	19.2	25.0	34.5	58.5	33.1	14.4	54.2	22.5	15.2	21.9	34.2	59.6
241	35.3	50.6	29.1	14.0	19.3	35.2	50.8	49.5	20.0	79.3	41.0	14.5	24.0	38.4	32.0
242	2.0	t	t	t	t	t	t	t	t	t	t	t	t	t	t
243	2.3	t	t	t	t	t	t	t	t	t	t	t	t	t	t
244	1.8	t	t	t	t	t	t	t	t	t	t	t	t	t	t
245	1.9	t	t	t	t	t	t	t	t	t	t	t	t	t	t
246	3.8	4.4	4.4	6.6	5.9	12.9	10.6	15.9	13.1	26.6	13.6	9.5	19.7	16.4	6.2
247	3.7	4.9	4.7	6.9	4.6	11.1	13.8	15.8	15.8	32.4	24.8	10.6	10.8	7.4	22.2
248	4.2	4.5	3.9	5.6	6.8	12.0	15.0	14.0	13.1	30.2	25.5	15.0	19.2	40.3	53.6
249	3.8	4.3	4.1	4.9	5.9	12.0	10.8	15.1	13.4	63.9	27.1	19.7	22.8	40.9	72.0
250	2.1	t	t	t	t	t	t	t	t	t	t	t	t	t	t
251	2.0	t	t	t	t	t	t	t	t	t	t	t	t	t	t
252	2.1	t	t	t	t	t	t	t	t	t	t	t	t	t	t
253	2.1	t	t	t	t	t	t	t	t	t	t	t	t	t	t
254	2.6	4.3	2.7	2.3	2.1	5.0	4.8	4.5	5.8	4.2	3.9	1.6	3.9	4.8	3.0
255	2.6	4.3	2.3	2.5	1.8	3.3	5.6	4.4	5.1	4.7	11.5	1.9	3.1	6.1	3.6
256	2.6	4.3	2.3	2.3	2.7	4.6	6.1	4.4	4.6	6.0	16.4	4.8	5.2	8.4	16.9
257	2.6	4.3	2.3	2.1	2.5	5.6	5.5	4.3	4.6	10.1	11.6	10.9	5.2	11.2	15.5

hibited in the entire dry land series but was less pronounced in those jars where nitrogen in the form of salt or green manure had been added.

It is of interest to note the rate at which the reduction of nitrates was brought about in the submerged soil. The nitrate content of the check jars at the beginning of the experiment averaged about 2.5 p. p. m. of nitrogen as nitrate. At the end of five days the nitrates in the flooded jars to which no nitrogen had been added had nearly disappeared. Still more striking is the reduction of nitrates in jar 231, a green manure jar, flooded late, as mentioned previously. Dry soil samples were taken from this jar for the last time on November 25 and contained 11.3 p. p. m. of nitrogen as nitrate. On November 26 this soil was flooded and when sampled again November 28 it contained but 1.9 p. p. m. On December 1 only a trace of nitrogen as nitrate was found. Even in those jars to which sodium nitrate had been added (234, 235, 236, 237), only a trace of nitrates remained after six weeks time had elapsed.

SOIL REACTION

Among the reasons offered for the failure of sodium nitrate to produce results with rice commensurate with those produced by ammonium sulfate is that suggested by Willis and Carrero (17). They proposed that the removal of the nitrate radicle with the consequent liberation of a basic ion, sodium, as a residue so changed the soil reaction toward alkalinity as to render the iron of the soil partially non-assimilable. In order to determine whether or not such a development occurs, determinations of hydrogen-ion concentration were made from certain jars. As time was limited for this work, samples of the flood water were withdrawn at intervals when it was sufficiently clear to permit readings to be made. In those cases where the flood water was turbid readings were not secured. Distilled water with a reaction of pH 6.5 was used for watering the plants. The hydrogen-ion determinations were made colorimetrically, using the Gillespie (6) method. These results are listed in Table 4.

TABLE 4.—*Soil reaction changes on variously treated rice soils.*

Jar No.	Treatment	pH values Nov. 5	Nov. 17	Dec. 6	Jan. 12	Jan. 27
226	Green manure, flooded, no crop	5.5	7.0	6.7	—	7.4
231	Green manure, flooded, cropped	5.5	—	7.3	—	7.2
235	$NaNO_3$, flooded, cropped	5.5	6.3	6.3	6.9	6.8
243	$(NH_4)_2SO_4$, flooded, cropped	5.5	5.3	5.3	5.9	5.7
244	$(NH_4)_2SO_4$, flooded, no crop	5.5	5.3	5.3	—	5.2
251	Check, flooded, cropped	5.5	5.9	5.7	6.5	6.5
253	Check, flooded, no crop	5.5	5.7	5.7	—	7.2

While the data here presented are not sufficient to enable one to draw definite conclusions, the evidence points to radically different changes in soil reaction in the submerged soils to which ammonium sulfate had been added as compared to those receiving sodium nitrate, green manure, or no treatment. The production of ammonia in rather large quantities from the green manure probably accounts for the reaction changes in those jars. The reason for the changes toward alkalinity in the sodium nitrate and check jars is less easily explained. Perhaps it is due to the removal of the nitrate radicle with the liberation of sodium and other basic ions, as suggested by Willis and Carrero.

RICE YIELDS AND FINAL ANALYSES

The rice plants were cut and removed from the jars on February 6, 93 days after they were transplanted. Previous experience had led the writers to believe that some physiological factor in the greenhouse invariably caused considerable "straighthead" and, therefore, that grain yields were not an accurate index to the relative value of various soil treatments. For this reason the plants were not allowed to go to maturity. Furthermore, the study of nitrogen changes in the soil was the matter of first importance in the experiment.

Removal of many soil samples from the jars undoubtedly injured the roots severely. In spite of this injury, however, the plants made good growth in all jars. The yields, therefore, appear to be a fair criterion of the relative value of the various treatments.

After removing the plants, the soil in each jar was thoroughly mixed and a sample taken for analysis. Ammonia, nitrites, and nitrates were determined as before. The results are not listed with those secured previously, as the interval between this analysis and the preceding one was not comparable to those between previous analyses. The oven-dry weights of the plants and the results of the final analyses are shown in Table 5. Only a trace of nitrites was found in any of the samples and they are therefore omitted. Results of duplicate jars are averaged.

The results in Table 5 point definitely to three conclusions as follows: (a) Ammonia was superior to nitrate as a fertilizer in both unflooded and flooded soil. This was true whether the ammonia was applied as ammonium sulfate or whether it came from decomposition of green manure. (b) A rather large amount of ammonia was taken up by the plants as shown by a comparison of cropped and uncropped jars. (c) In the unflooded jars nitrates were assimilated to considerable extent by the rice plants.

TABLE 5.—*Yields of rice straw and final soil analyses on variously treated rice soils.*

Jar No.	Treatment	Yield of rice straw in grams	Concentration of nitrogen in p.p.m. As ammonia	As nitrates
226–227	Green manure, flooded, no crop	—	26.5	trace
228–229	Green manure, flooded, no crop	—	24.4	trace
230–233	Green manure, not flooded, cropped	10.0	1.6	50.2
231	Green manure, flooded, cropped	9.8	11.0	trace
232	Green manure, not flooded, no crop	—	3.2	68.0
234–235	$NaNO_3$, flooded, cropped	9.7	2.8	trace
236–237	$NaNO_3$, flooded, no crop	—	9.2	trace
238–239	$NaNO_3$, not flooded, cropped	5.5	trace	17.9
240–241	$NaNO_3$, not flooded, no crop	—	trace	44.0
242–243	$(NH_4)_2SO_4$, flooded, cropped	11.4	3.4	trace
244–245	$(NH_4)_2SO_4$, flooded, no crop	—	10.6	trace
246–247	$(NH_4)_2SO_4$, not flooded, cropped	9.1	trace	15.9
248–249	$(NH_4)_2SO_4$, not flooded, no crop	—	9.6	84.6
250–251	Check, flooded, cropped	8.4	3.6	trace
252–253	Check, flooded, no crop	—	11.3	trace
254–255	Check, not flooded, cropped	4.2	trace	3.2
256–257	Check, not flooded, no crop	—	trace	26.2

DISCUSSION OF RESULTS

It has been mentioned previously that considerable variation may be noted in the nitrate data and also in that applying to ammonia. There are probably several reasons for these variations. The necessity of using small samples so as to prevent too excessive injury to the plants is probably one of the main contributing factors. It did not seem desirable to sample the jars each time in a considerable number of places for a composite sample because of injury to the plants. The amount of water in the jars affected the volume of the system, and hence, the concentration in the submerged soils. Because of the constantly changing weight due to removal of samples, no attempt was made to keep the ratio of soil-to-water constant. The comparatively large variations in nitrates and ammonia in the soils treated with ammonium sulfate and sodium nitrate indicate that the writers failed to obtain a uniform distribution of the salts in these soils. The rather close agreement of the averages of all analyses shows that technic in determinations was not at fault.

Utilization of nitrates by bacteria and the natural variation between samples were other factors probably affecting the nitrate data. The nature and extent of such variations has been pointed out by Brown and Gowda (1), Coleman (3), and Waynick (16).

The results secured with sodium nitrate are in general accord with those obtained by previous investigators. The writers do not

believe that the inferiority of nitrates as compared with ammonia may be due to the formation and accumulation of nitrites, as suggested by Kelley (7).

The plants in soil treated with sodium nitrate and submerged showed symptoms similar to chlorosis, while those treated with ammonium sulfate retained a dark green color. This difference may have been due to difference in nitrogen assimilation, since the nitrogen in the sodium nitrate treated jars, after nitrates had been reduced, may not have been readily available to the plants. In solution cultures amino nitrogen was assimilated, though not so readily as ammonia. The partial chlorosis in the nitrate jars may have been due to inability of the plants to assimilate sufficient iron after the reaction of the soil had been brought near the neutral point. This is being investigated further in work now under way in which also an attempt is being made to determine whether or not nitrogen is lost from flooded soils as a result of nitrate reduction.

In view of the unsatisfactory results secured with green manure where the soil was flooded immediately, it seems probable that excess free ammonia accumulation may result under these circumstances from heavy applications of green manure. This was indicated by the alkaline reaction developed in these jars. The ammonia produced in the non-submerged, green manure treated jars, although only showing in the analyses at times, appears to have stimulated growth markedly. It is interesting to note that though the reaction in the submerged green manure treated jar (231) became slightly alkaline, the plants grew well and developed less chlorosis than those treated with sodium nitrate.

SUMMARY

1. Nitrate, nitrite, and ammonia changes were studied in flooded and unflooded soils under greenhouse conditions. These soils were treated as follows: Green manure, sodium nitrate, ammonium sulfate, and no treatment. One-half of each series was cropped to rice and the other half left uncropped. The results from a study of these changes indicate that the nitrite content of the soil was never significant at any time. The greatest concentration was 0.25 p. p. m. No toxic effect to the plant could be expected at this concentration.

2. In soils to which ammonium sulfate was applied the following changes in ammonia were observed: For the unflooded series ammonia decreased from about 27.5 p. p. m. to a trace over a period of two months. During the same time the nitrates increased from 4 p. p. m. to about 27.5 p. p. m. and one month later they had de-

creased to 13 p. p. m. In the flooded series the ammonia decreased from about 20.5 p. p. m. to 11 p. p. m. in two months. The nitrates in this series were not readable after the first analysis. Nitrates were greatly reduced in the unflooded soils as a result of cropping. After a period of two months the cropped soils showed 14 p. p. m. of nitrates in comparison to 62.4 p. p. m. in soils not cropped.

3. The changes of nitrates in soils to which sodium nitrate was applied are as follows: In submerged soils the nitrates decreased from 19 p. p. m. to a trace two months after cropping. The ammonia in the same soil, during the same time usually was not readable, though in a few cases a concentration of 6 p. p. m. are recorded in the flooded soils. For similar unflooded soils the nitrates were reduced from about 41 p. p. m. to 18 p. p. m. over a period of two months. During this time traces of ammonia are recorded. It appears that in this case nitrates were assimilated by the rice plant.

4. The submerged soils to which green manure had been applied showed a steady increase (over a period of two months) from 4.1 p. p. m. to 34 p. p. m. of ammonia. During this time the nitrates were present in too small a quantity to be readable. In the dry soils the ammonia increased from a trace to 9 p. p. m. in two weeks and then decreased again to a trace after a period of six weeks. During this time the nitrates increased from 3 p. p. m. to 56.5 p. p. m.

5. Soil reaction was changed decidedly toward alkalinity in flooded soils treated with green manure, with sodium nitrate, and those receiving no treatment. No such change occurred where ammonium sulfate was applied.

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A DRYING HOUSE FOR THE RAPID HANDLING OF FORAGE SAMPLES[1]

T. E. Odland and R. J. Garber[2]

In field experiments involving the determination of yields of forage crops one of the difficult problems is to find a method of drying the samples for moisture determination quickly and efficiently. Where facilities are at hand for reducing the samples to a moisture-free basis, this is the most desirable method. However, such facilities are often lacking, since the capacity of the ordinary drying oven is so small that only comparatively few samples can be handled at a time.

Some experiment stations have followed the practise of taking samples at the time of determining the field weights, weighing the samples at that time, and then again after the samples have become thoroughly air dry. From these weights the air-dry yields are calculated. This method is open to the objection that the actual moisture content of the sample, when air dry, may vary somewhat with the humidity of the air

The use of the actual field weights of forage crops without making corrections on the basis of moisture determinations is very unreliable on account of the varying moisture content of the material being weighed. If the proper time to consider hay as cured is left to the judgment of an individual, the standards are obviously likely to vary between rather wide limits.

The method that was in use at the West Virginia Experiment Station until recently was to take a sample consisting of from 5 to 15 pounds, depending on the material being weighed, at the time that the field weights of the crop were determined. In some experiments the weighings were made immediately after cutting, while in other experiments they were made after the crop was considered sufficiently cured for hay. The sample was placed in a weighed cotton bag and its total weight determined. The bag containing the green or field-cured sample was then hung up in a small drying house where a temperature of as nearly 55° C as possible was maintained with a coal heater. Openings near the floor and an outlet vent provided ventilation. The sample was left in this drying house until it was thoroughly dry, and then it was taken out and hung up in a shed until it had reached a relatively constant weight. The air-dry weight was de-

[1]Contribution from Department of Agronomy, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Approved as scientific paper No. 45 by N. J. Giddings, Acting Dean and Director, West Virginia College of Agriculture and West Virginia Experiment Station. Received for publication February 24, 1928.

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termined several weeks later. Care was used to do the final weighing only after a number of successive clear days. From these weights the air-dry yields were calculated.

Although this method of handling the samples gave fairly uniform results from season to season, it was rather slow and it was also inconvenient at times to do the weighing when the weather was favorable. In order to overcome these difficulties, the following described building was planned and built. It was used during the past crop season with very satisfactory results. Fig. 1 shows roughly the floor plan.

The drying house is constructed of hollow tile and has a stucco exterior. The drying room is 20 x 20 feet and 10 feet in height.

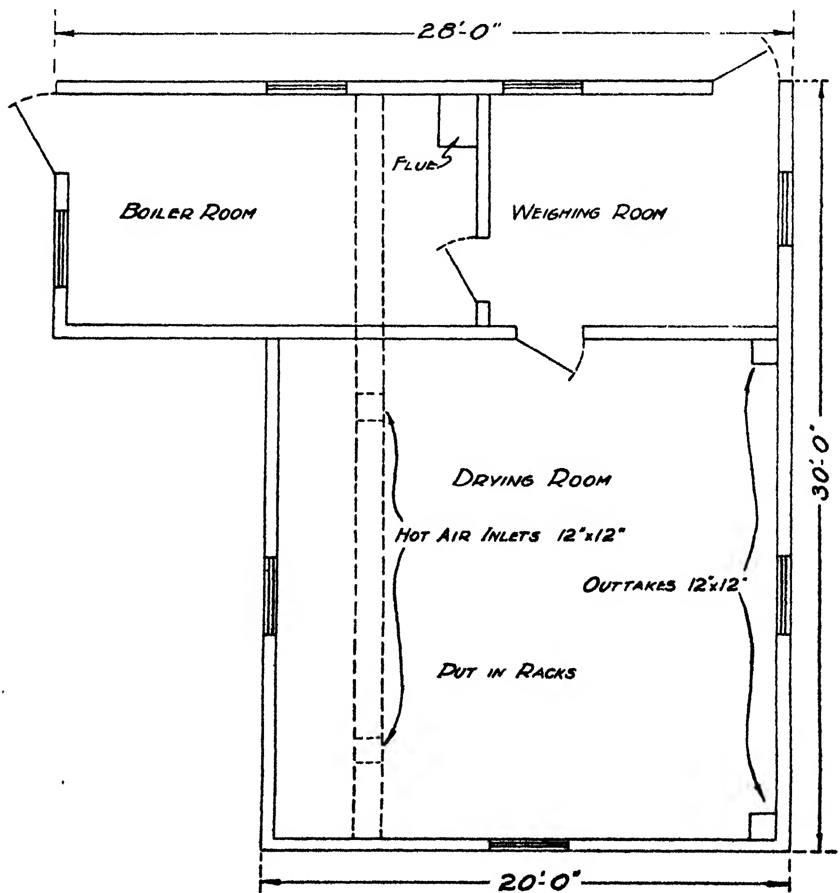

FIG. 1.—Sketch of floor plan for drying house in use by the Agronomy Department of the West Virginia Experiment Station. (Drawings and sketch by F. D. Cornell, Department of Farm Economics.)

It will accommodate about 1,000 samples at a time. This room has a double ceiling overhead. Air is drawn from the outside, conducted over a three-section Areofin copper tube steam radiator, and forced into the drying room. An electrically driven Sirocco fan is used to force this air circulation. The air outlet ducts have their openings near the floor and the hot air is forced in near the ceiling.

The samples are taken as formerly and hung up in the drying room where a temperature of 55° C is maintained. An automatic control keeps the room within a few degrees of this standard while the plant is in operation.

It was found that samples handled in this way could be dried to a moisture content of from 1 to 3% by leaving them in the drying room for 48 hours. If the material had been partly dried in the field before the samples were taken, considerably less time was needed.

In order to check the reliability and uniformity of the results obtained with this method of drying, 10 samples each of timothy, soybeans, clover, alfalfa, and corn silage were oven dried after going through the drying room. The corn silage and soybean samples were put into the drying room when green, while the others had been field cured. The results obtained are shown in Table 1.

TABLE 1.—*Means and standard deviations of the moisture content of samples of different forage crops dried in the drying house used on the Agronomy Farm of the West Virginia Experiment Station.*

Material	Means %	Standard deviations %
Soybeans	1.61 ± 0.03	0.13 ± 0.02
Corn	1.91 ± 0.09	0.42 ± 0.06
Clover	2.04 ± 0.07	0.33 ± 0.05
Timothy	1.23 ± 0.04	0.17 ± 0.03
Alfalfa	1.58 ± 0.06	0.28 ± 0.04

Although it was not possible to reduce the forage samples to an absolute moisture-free basis by the methods described, it is believed the results obtained are sufficiently accurate for all ordinary purposes in field trials with forage crops.

As is shown by the data in this table the mean moisture content in these samples varied from $1.23 \pm 0.04\%$ for timothy hay to $2.04 \pm 0.07\%$ for clover hay. These figures show that the samples could be reduced to a very low moisture content in this drying house.

The variability in the moisture content is indicated by the standard deviations. These varied from $0.13 \pm 0.02\%$ for soybeans to $0.42 \pm 0.06\%$ for corn. The figures indicate that the variation among the samples from corn was greater than from the other crops. In general, the samples were satisfactory in regard to uniformity of moisture content.

THE CORRECT EXPLANATION FOR THE HEAVING OF SOILS, PLANTS, AND PAVEMENTS[1]

George J. Bouyoucos and M. M. McCool[2]

The heaving of soils on freezing is a commonly known phenomenon. Its occurrence is general but varied. Its effects are usually harmful. These harmful effects consist in uprooting cultivated plants, especially seedlings of clover, alfalfa, wheat, oats, etc., and raising up and cracking road pavements. The effects of heaving are very powerful and the injuries resulting therefrom can be very serious.

The usual explanation of heaving is that it is due to the upward expansion of water upon freezing. This explanation according to our recent studies, however, is almost entirely wrong. It is the object of this paper to give what seems to be the correct explanation of the phenomenon, and to present experimental data supporting it.

CORRECT EXPLANATION OF HEAVING

The heaving of soils is not due to the mere expansion of water upon freezing, as is universally believed, but rather and almost entirely to the accumulation or drawing of water at or near the surface upon freezing, and to the building up of this water into capillary ice columns or long needle-like crystals, or in some cases, into solid ice. It seems to be the peculiar phenomenon of crystallization that when water freezes it draws to itself unfrozen water, that this frozen water grows in size, and that the form of growth will vary according to conditions. It seems that the fundamental principle underlying nearly all forms of heaving of soils, plants, and pavements is the phenomenon of the accumulation or drawing of water to itself upon freezing by the force of crystallization and the upward growth and pushing of this frozen water.

There are two main factors controlling, or greatly modifying, the phenomenon of heaving. These are moisture content and rate of freezing. There must, of course, be plenty of moisture for heaving to take place. The minimum appears to be appreciably below the water-holding capacity point. Providing there is plenty of moisture in the soil, there are two main forms of heaving that may take place according to the rate of freezing. If the temperature goes down slowly and gradually and does not drop too low, say 20°F, then the film of water at the surface of the soil begins to freeze and as it freezes it draws water from the lower depths of the soil and grows into ice

[1]Contribution from Department of Soils, Michigan State College, East Lansing, Mich. Received for publication February 27, 1928.

[2]Research Professor and Head of Department, respectively.

capillary columns or long needle-like crystals as shown in Figs. 1, 2, and 3. If the air temperature remains at or below the freezing point, these ice capillary columns will continue to grow, assuming considerable heights, sometimes 5 inches, especially where the moisture content is high, as in muck soils. The growth for each night occurs by steps as indicated by Fig. 4. These capillary columns would be

FIG. 1.—Column of ice of thin capillary tubes or needle-like crystals formed at the surface of a well-drained sandy loam. The force of crystallization brings the capillary water to the surface, and as it freezes into these massive capillary tubes, the whole column is pushed upward as the growth takes place at the lower end. This shows how plants may be pushed out of the soil by these ice columns.

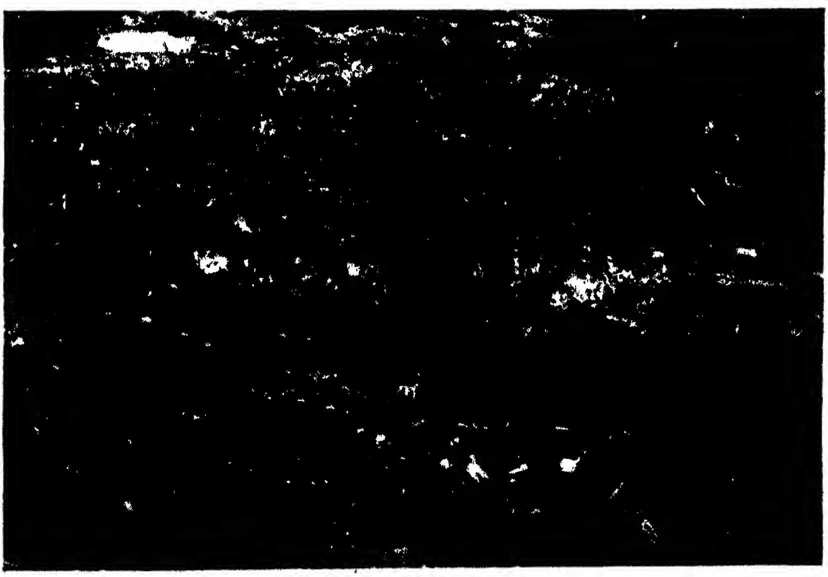

FIG. 2.—The same phenomenon as shown in Fig. 1, but on a loam soil on low and wet ground.

formed at the surface of the soil without penetrating the lower depths, or even without the surface soil being frozen, growing upwards as straight needles or thin capillary tubes massed together. The growth seems to take place at the lower end and push the entire column upward, as the capillary tubes are elongated from below. The ice column in Fig. 3 is 4½ inches high and was formed during three nights. At the top of the ice capillary columns there may be

FIG. 3.—Same phenomenon as in Fig. 1, but on a muck soil.

a veneer of soil with pebbles etc., which may be taken deceptively as the surface of the soil.

The texture and structure of the soil may influence sometimes the form of the ice that is formed at the surface. If the soil is heavily compacted, the ice may be formed at the surface not as capillary tubes but rather as solid ice. This seems to be true also in well settled clay soils. However, it cannot be stated definitely that in all compacted, and in all clay soils that are fairly compact the ice formed at the surface will be more or less solid and not capillary in form.

The manner in which the water is drawn to the surface by the force of crystallization is capillary. To what depth in the soil this water will be drawn from has not been definitely determined, but it may be several inches on any extended time. It is local at any given time and then progressive on any extended time. The force of crystallization which draws the water is so powerful and efficient that it can reduce the water content of the soil to a comparatively low point, or until the continuous capillary film is broken. It must be remembered also that the phenomenon of surface tension comes into play as the equilibrium is disturbed by the withdrawal of water.

This pulling force of freezing which brings the water to the surface to freeze is very similar to the pulling force of evaporation. The former, however, seems to be more powerful than the latter.

If the moisture content of the soil is quite low there is hardly any movement of moisture to the surface to freeze. Instead, the moisture freezes in the larger capillary spaces as snow or ice particles as shown in Fig. 4. Even in this case, however, the fundamental principle of pulling and moving operates. What happens here is that the water in the larger capillaries, upon freezing, draws upon itself by the force of crystallization the water from the finer or smaller capillaries and films around the soil particles, and grows at their expense. This particular point has previously been discussed in detail.[3]

FIG. 4.—Snow or ice particles formed when the moisture content of a soil is low. Instead of the water rising to the surface and freezing into capillary tubes, it freezes in the soil, chiefly in the bigger capillaries.

Although water will also tend to move in the form of vapor from the high temperature in the lower depths to the low temperature at the surface, the amount will be extremely small for a period of overnight and would not account for the results obtained. This conclusion is based upon researches conducted at this laboratory on the thermal movement of moisture in soils,[4] and also upon the fact that the gradient of temperature between the point where ice is formed and the unfrozen soil below is too small for any vapor pressure to develop.

The foregoing type of heaving wherein ice accumulates at the surface of the soil occurs, as already stated, when the temperature falls slowly and gradually and does not go down too low. There is a second type of heaving that takes place when the temperature falls all of a sudden very rapidly and low and then moderates slightly.

[3]Bouyoucos, G. J. Movement of soil moisture from small capillaries to the large capillaries of the soil upon freezing. Jour. Agr. Res., 24:427–432. 1923.

[4]Bouyoucos, G. J. Effect of temperature on movement of water vapor and capillary moisture in soils. Jour. Agr. Res., 5: 141–172. 1915.

Frequently, in the fall and spring there are warm spells with heavy rain followed suddenly by a cold wave when the temperature may drop overnight from 50° to 15°F. Under these conditions the following type of heaving may occur. The surface soil 1 or 2 inches is frozen solid. The freezing is so rapid that the force of crystallization has not time to draw water from below and bring it to the surface to freeze as capillary columns or even as solid ice. Instead, the soil freezes solid with its original water content. After the upper layer of 1 or 2 inches of soil is frozen and the air temperature moderates somewhat, then immediately under the frozen layer there begins to be formed and grow the capillary columns of ice. These capillary columns of ice grow upward and as they grow they must push frozen layers above upward because they disconnect the frozen layer above from the unfrozen soil below and there is only the ice columns between. If these ice capillary columns are taken out, there is an empty space or cave between the frozen layer above and the unfrozen soil below. Fig. 5 illustrates this phenomenon. This phenomenon can always occur in organic soils, but may not always take place in mineral soils, especially compacted soils. In the case of the mineral soils, it is more apt to take place when they are loose after cultivation. In the case of the organic soils the space created between the frozen layer above and the unfrozen soil below may be of considerable height. The measurements in some cases were over 4 inches.

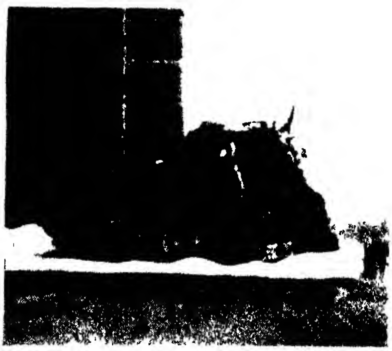

FIG. 5.—When the temperature of the air drops rapidly and to a low point, the upper 1 inch of soil freezes solid without any water moving to the surface to freeze as capillary tubes. Just below this solidly frozen layer the capillary tubes of ice begin to form and to push up on the frozen layer above.

A third type of heaving may be due to the mere expansion of the water in the soil upon freezing since water expands about one-eleventh of its volume upon freezing. Apparently this is the type of heaving that is generally thought of. It is believed, however, as a result of these researches, that the mere expansion of water upon freezing into solid ice, causes practically no heaving in soils. Where there is standing water there will be, of course, an increase in volume when this water is converted into ice, but this kind of expansion in volume

will not heave out plants. In ordinary soils the mere expansion of their water content upon being frozen into solid ice would not heave them at all. The heaving of soils takes place by either one or both of the first two types described and not by the third, and between the two the first is undoubtedly the most common and most destructive.

The general impression prevails, or at least the text books of soils state it, that heaving of soils occurs mainly in poorly drained soils, and that if these soils are drained they will not suffer heaving. While it is true that poorly drained soils are apt always to be subjected to heaving, yet heaving can take place even in well-drained soils. Heaving takes place in the fall and spring when all the soils are apt to be wet after rains or the melting of snows or due to slow drainage. Under these conditions, therefore, even well-drained soils can heave.

HOLLOW SPACES UNDER ICE SHEETS

As further evidence that water is drawn upwards upon freezing by the force of crystallization may be cited the hollow spaces that exist under ice sheets where water has stood in mud holes or other places. It is commonly observed that when standing water freezes in mud holes or other places, there are nearly always hollow spaces under the ice sheet, as shown in Fig. 6. The universal explanation for the hollow space under the ice sheet is that part of the water

FIG. 6.—Hollow spaces below ice sheets which are due to the ice sheets being heaved or pushed up by ice ridges, pillars, or capillary tubes.

froze to form the ice sheet and the remainder drained into the ground. While this explanation may be partly true in some cases, the correct explanation is that the hollow spaces have been formed by the ice sheet having been pushed up or heaved by ice columns that are formed by the rise of water in the soil upon freezing. In other words, the same principle that has already been described as causing the heaving of soils, also holds true here.

The manner in which the ice sheets are heaved varies tremendously according to conditions, but two types may be described which are believed to be characteristic of most cases. In the first case it may be assumed that there is a depression produced by the foot of a horse and this depression is covered with a shallow depth of water. When the temperature falls to the freezing point the soil around the depression begins to freeze first and to draw water from the depression. After a time the water in the depression has also frozen into an ice sheet. This ice sheet, of course, is connected to the edges of the depression and since water moves upward as it freezes at these edges, the ice sheet is pushed upward also. After all the standing water in the depression has frozen, the freezing which is now taking place at the edges of the hole will draw water from the wet soil itself, and thus push the ice sheet to considerable heights, sometimes considerably above the highest points of the edges of the depression. The ice at the edges of the depression which pushes the entire ice sheet upward may be only a thin film or a thin pillar at some point.

In the second form of typical heaving of ice sheets a fair sized depression with irregular bottom and covered with water may be considered. When an ice sheet has been formed and begins to touch the soil at the shallowest points, ice columns or pillars begin to be formed there. These ice columns draw water either from the soil itself or from the standing water in the deeper points of the depression, hence they grow in height and as they grow push up the entire ice sheet, sometimes to several inches, and thus create a hollow space below. These ice columns assume various forms; they may be regular pillars, they may be a mass of capillary tubes, or they may exist in a continuous form of ridges as shown in Fig. 7. Sometimes just one pillar at a certain point in a large area of the ice sheet will raise the entire ice sheet evenly.

QUANTITATIVE DATA

In addition to the illustrations which show the upward movement of water upon freezing, it is of interest to report here some quantitative data. Some of these data are most striking. For instance,

on an area of 12 square inches on a muck soil there arose above the surface overnight 285 grams of water in the form of ice capillary columns as shown in Fig. 2. The moisture content of this soil before freezing was 118%. In a loam soil which had a moisture content of 32% there arose overnight 56 grams of water. In a clay soil which had a moisture content of 40% there arose 72 grams of water, and in a sandy soil which had a moisture content of 18% there arose 25 grams of water. The area on which the ice was collected was 12 square inches in every soil. In collecting these samples of ice, an attempt was made to include as little of the soil as possible.

These results are certainly most striking, and they serve to explain why soils are so wet at the surface after they are frozen, while they

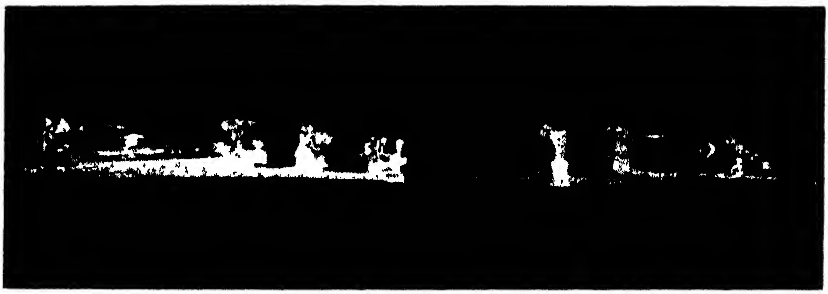

FIG. 7.—Ridges or ice pillars formed under ice sheets which exert a heaving or pushing effect on the latter.

were not at all wet before freezing. Even when ice crystals are not visible at the surface, an accumulation of water has taken place nevertheless.

This phenomenon of the accumulation of water at the surface upon freezing raises the question of the accumulation of salts at the surface. There is, of course, no question but what considerable amounts of salts from the soil must be carried to the surface by the process of movement of water.

HEAVING OF PLANTS

One of the injurious effects of heaving is the killing of plants, especially seedlings of clover, alfalfa, wheat, etc., by their being pushed completely out of the soil. It is a common occurrence to see a field of seedling clover or alfalfa lying with their roots exposed on the surface of the soil.

The question now is, How are the plants heaved and by which one of the types of heaving?

A careful consideration of the subject shows that most, if not all, of the heaving of plants takes place by the first type—that is, where the water accumulates at the surface and grows upward into capillary ice columns, or into ice sheets. Undoubtedly some heaving of plants takes place also by the second type where the ice crystals grow under the frozen surface layer.

It is plain to see how plants could be easily heaved out of the ground by the first type of heaving. The ice sheet or crystals which are formed at the surface of the soil attach themselves to the plants, either at the crown or trunk, and hold on with great force. Since the ice sheet or crystals grow from below, i.e., next to the surface of the soil and push upward, the plants are pushed along and will be pulled out of the ground to the corresponding height of the ice sheet, or crystal, to which they grew. If warm weather comes, the ice sheet and crystals are melted and the plants are left out of the ground. If after the warm weather, cold weather comes and the ice formation is repeated, the ice sheet grips the plants at a point level with the surface of the ground which may be far below the original or previous point and pulls the plants still further out of the ground. If this process of freezing, thawing, and pulling of the ice on the plants from points lower down is repeated a sufficient number of times, the plants will be pulled out entirely.

The extent to which the plants will be pulled out of the ground by this process will depend (1) upon the kind of plant, (2) moisture content, and (3) number of times of freezing and thawing.

Seedlings of clover and alfalfa will be pulled out more easily than wheat because the former do not have such an extensive root system as the latter.

If the moisture content of soils is very high, the height to which the ice sheet or crystal will rise will be correspondingly high and consequently the plants will be heaved out much more than if the water content was low and the ice sheet did not rise very high. In muck soils where the water content is high the plants could be pulled out of the ground 2 or 3 inches in a single night's freezing. In sandy soils, even if saturated, the water content is not so great and the ice sheet does not rise so high. Consequently the plants may never be entirely heaved out even under repeated freezing and thawing, but may be only partially heaved.

The pulling out of plants by the ice sheet formed at the surface is greatly facilitated by the fact that the soils are so wet and soft just at those seasons when heaving occurs that they have very little holding power on the plants. The soils are abnormally wet at these

seasons on account of poor drainage due to frosts or low temperature which affects the viscosity of water.

In the second type of heaving wherein the surface soil freezes and the ice sheet formed immediately below pushes up the frozen layer, it can also be readily seen how plants can be heaved out of the soil. The frozen layer of soil is also frozen on the plants and if the frozen layer is pushed upward by the ice below the plants are also pushed upward. When the frozen layer and ice sheet below thaw out and the soil settles, the roots of the plants prevent them from getting back to their original position. If these processes of freezing and thawing are repeated, the plants might be entirely heaved out. As already stated, however, this form of heaving of both soils and plants may not be so common among mineral soils as in mucks and peats.

HEAVING OF PAVEMENTS

The principle, in one modification or another, that underlies the heaving of pavements is also based on the natural tendency of water to move upwards and accumulate at the points of freezing; the movement and accumulation being impelled by the force of crystalization The water that is drawn and accumulated at the points of freezing may freeze as solid ice, as a solid sheet of ice with strong pillars, as ridges growing under and pushing the sheet upwards, or as a mass of capillary tubes. Whatever form of ice the water assumes upon freezing, the upward push of this growing ice is apparently sufficient to heave pavements.

The principle that it is desired to emphasize in the heaving of pavements is that the heaving is not caused only by the mere expansion of the water already present under the pavement upon freezing, but also by the accumulation of more water from the surrounding area and by the peculiar forms of ice that the water assumes upon freezing. Probably there are very few cases where pavements have been heaved only by the mere expansion upon freezing of water already present. It would seem that unless the freezing is extremely rapid there must always be a movement of water to the point of freezing. This would be true even in pockets of water under the pavement.

Considering the great weight of the pavements, it would seem that there must be present large amounts of water to freeze in order to lift such heavy weights. On the other hand, if the water freezes in the form of pillars, there need not be such a large amount present, because these pillars usually grow at the shallowest points and can draw water to themselves from the deeper surrounding depression, as well as from the soil below, and as they grow upwards they exert

a powerful leverage or wedge on the pavement. On the whole, however, heaving of pavements occurs at places of poor drainage and at places where, one way or another, water gets under the pavement, and may be due to either type of heaving described above.

The conditions under which pavements are heaved are so numerous and varied that they cannot all be discussed here. The fundamental principle discussed above, however, will hold in all of them to a lesser or greater degree.

PREVENTING HEAVING

There appear to be two possible ways of preventing the heaving of plants. These are (1) draining the soil and (2) preventing them from freezing.

The draining of soils, however, will not always prevent heaving of plants, because even well-drained soils will heave. This is due to the fact that in the late fall, and especially in the spring after the melting of snow, drainage is poor due to frosts and low temperature. This affects the viscosity of water. Also, all soils are more or less supersaturated. These are just the periods when heaving occurs. A poorly drained soil, however, is apt always to heave and if it is drained there may be many seasons when it will escape heaving. Furthermore, if there is not too much water in the soil the damage to plants may not be so severe as previously stated.

If soils can be prevented from freezing, the heaving of plants can, of course, be completely prevented. It is possible to prevent soils from freezing by covering them with straw or something similar. This, however, is not always possible when the temperature drops quite low, but in the spring when most of the heaving ususally takes place, the temperature does not ordinarily drop so low, and it is possible to prevent heaving on such occasions by a dressing of straw or something similar. However, to what extent these statements are correct, will be answered by a series of experiments that are being conducted upon this subject.

The prevention of heaving of pavements would seem to depend on (1) a complete drainage of the soil, (2) preventing water from entering and accumulting under the pavement, and (3) having a porous bed of stone under the pavement. With the principles stated above in mind, the road engineer is in a better position to work out or suggest ways of preventing the heaving of pavements.

SUMMARY

In this paper the correct explanation is given of the phenomenon of heaving of soils, plants, and pavements.

The old explanation that heaving is caused by the expansion of water upon freezing is found to be wrong.

The true explanation appears to be that heaving is caused almost entirely by the drawing or accumulation of water on freezing at or near the surface by the force of crystalization. This frozen water grows upwards in the form of massive capillary ice columns, pillars, ridges, or solid sheets of ice. As water is pulled or drawn to the points of freezing and as these different forms of ice grow upward, they push upward.

This is a general fundamental principle and, in one modification or another, underlies nearly all the phenomena of heaving of soils, plants, and pavements.

SOME PLANT CHARACTERS DETERMINING YIELDS IN FIELDS OF WINTER AND SPRING WHEAT IN 1926[1]

KARL S. QUISENBERRY[2]

INTRODUCTION

Agronomists who work with wheat are constantly striving for larger yields. Plant breeders and crop and soil investigators are endeavoring to produce or find varieties with better yielding ability, and rotations or cultural methods which will cause a given variety to produce more grain per acre. Investigations have been conducted to determine what characters of the plant are most closely associated with yield. It is realized that yield is the final result of a large number of interacting environmental and plant factors. As the wheat plant stands in the field at harvest time, some of the more important characters determining yield are number of heads per unit area, number of kernels per head, and weight of kernels.

Sprague (3)[3], working with Nebraska No. 60 wheat grown at Lincoln, Nebr., in 1921 and 1922, found that there was a high positive correlation between yield per unit area and average number of spikes per area. Smaller positive correlation was found for yield per unit area with grain yield per spike and weight per kernel. For spring and winter wheat in nursery experiments in Minnesota in 1926, Hayes, Aamodt, and Stevenson (1) found that plumpness of grain was rather highly correlated with yield.

Under field conditions it is a question whether it would be better to have thick stands at a possible expense of head size or to have thin stands and larger heads. Martin (2) has pointed out that the larger heads which accompany thinner stands have frequently deluded farmers in semiarid regions into believing that thin stands produce the highest yields. From the standpoint of the plant breeder, it is of interest to know if varieties should be developed which tend to produce more heads per plant or varieties with fewer but larger heads. It is also important to know whether the number of heads can be increased without decreasing the kernel size or plumpness. It is fully realized that environment will have a great influence on the relation of these characters, and that the effects will not necessarily be the same each year.

[1]Contribution from Western Wheat Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication March 5, 1928.

[2]Associate Agronomist.

[3]Reference by number is to "Literature Cited," p. 499.

MATERIALS AND METHODS

During the summer of 1926, the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, in cooperation with the Divisions of Agricultural Engineering, Bureau of Public Roads, and of Farm Management and Costs, Bureau of Agricultural Economics, also of the Department, and with certain state experiment stations, investigated the efficiency of the combine or combined harvester-thresher. In determining the percentage of loss in harvesting it was necessary to obtain some measure of the original yield of the wheat in the field under study, as well as the amount of grain per head. The method used in obtaining this information was to cut the heads from 24 4-foot lengths of drill row taken at random in the field. The area sampled was equivalent to three rod-rows spaced 1 foot apart for fields sown in 6-inch drills. Eight samples of 4-foot strips were put into a single sack, thereby making three sacks from each field. All sacks were shipped to Washington, D. C., where the number of heads per sack was determined, the samples threshed, and yields per area obtained. Knowing the width of drill rows, the yield per acre could then be calculated. This yield, compared with machine yields, might give some indication of losses.

Samples were obtained from winter wheat in Alfalfa County, Oklahoma, Ottawa and Cloud Counties, Kansas, Perkins County, Nebraska, and Judith Basin and Fergus Counties, Montana. In the two Montana counties samples also were obtained from spring wheat. The winter wheat consisted almost entirely of the rather similar hard red winter varieties Turkey, Karmont, Kanred, and Blackhull, while the spring wheat was all Marquis and Red Bobs. In the samples from Oklahoma, Kansas, and Nebraska the heads were counted from only one sack from each field, although the yield was determined from the average of the three samples from each field. For the Montana samples both head counts and yields were determined for each sack.

From each sample 1,000 kernels were weighed to determine the average weight per kernel. It then was possible to calculate the average number of kernels per head, giving a figure useful in determining losses where head counts were made after the binder, header, or combine.

CORRELATION BETWEEN CALCULATED YIELD AND YIELD AS REPORTED BY THE FARMER

In completing the survey, each farmer was visited after he had finished threshing and a report on the actual yield per acre was

obtained. The yield reported by the farmer took into consideration his entire acreage, while the yield sample was taken from a portion of only one of the farmer's fields. The farmer's report of yield was based on an acreage which in some cases might not have been absolutely correct and on a total number of bushels which was in some cases an estimate. While the accuracy of such a reported yield may be questioned, it is felt that it is a close approximation of the true yield.

In Table 1 is presented the correlation surface, comparing the yields as calculated from the samples with the yields as reported by the farmer. In all, comparable data from 166 different farmers, located in the four states mentioned, were used. Owing to small numbers it was desirable to group all the data together, rather than to attempt to compute a coefficient of correlation for each state. The coefficient, $+0.5909 \pm 0.0347$, shows that in most cases the estimate from the sack sample gave an approximation of the actual yield. There were a few cases where the calculated yields were much higher than the reported yields. These wide differences may be due to errors in taking the samples, or to the sample having been obtained from a small field which yielded more than the rest of the farmer's acreage. The calculated yields did not make allowances for harvesting and threshing losses. No doubt these discrepancies all had an effect in reducing the correlation. It would seem, however, that in general, the method of estimating yield from field samples was fairly accurate, and had the actual yields been available from each field from which samples were obtained, the correlation probably would have been higher.

TABLE 1.—*Correlation between yield in bushels per acre as obtained from field samples and yields as reported by farmers.*

Yields from field samples, Bushels per acre	Yields as reported by farmers, Bushels per acre: 5	8	11	14	17	20	23	26	29	32	35	38	Total
2.5		3	1										4
6.5	2	3	6	2									13
10.5		2	4	5	2	0	1						14
14.5		3	5	5	2	1							16
18.5		4	5	6	3	10	1	3					32
22.5		2	6	4	4	6	2	7					31
26.5			3	5	1	7	4	2	0	0	1		23
30.5				2	0	3	7	2	2				16
34.5				1	0	0	1	2					4
38.5			1					2	2				5
42.5			1	0	1	1	1	0	1			1	6
46.5													0
50.5					1				1				2
Total	2	17	32	30	14	28	17	18	6	0	1	1	166

$r = +0.5909 \pm 0.0347$

PLANT CHARACTERS INFLUENCING YIELD

As previously stated three sacks of heads were sent to Washington, D. C., from each field observed during the combine study. Each sack contained eight 4-foot lengths of drill row taken at random in the field. For each field it was then possible to determine yield per unit area, number of heads per unit area, number of kernels per head, and weight per 1,000 kernels. By the use of correlation coefficients it is possible to determine which of the three factors mentioned had the greatest influence on yield. In these correlations, grams per unit area is used as the measure of yield.

The following tabulation shows the number of fields entering into the calculations for each of the states:

State	Class of wheat	Number of fields
Oklahoma	Hard red winter	42
Kansas	Hard red winter	28
Nebraska	Hard red winter	91
Montana	Hard red winter	36
Montana	Hard red spring	76

The number of observations is small in most cases, but since the environmental conditions in the several states are different, it is felt that each state must be considered separately.

Table 2 presents the simple correlation coefficients obtained. A study of these shows that in most cases the correlations for yield with number of heads, weight of 1,000 kernels, and kernels per head are fairly high and statistically significant in the light of their probable errors. The one exception is the low correlation between yield and weight of 1,000 kernels in Nebraska. No single character gave the highest correlation with yield in all cases. In Oklahoma, Nebraska, and Montana spring wheat number of heads gave the highest correlation, while in Kansas and Montana winter wheat kernels per head seemed the most important character. In no case did weight of 1,000 kernels give the highest correlation with yield, although different results might have been obtained had the yields been affected by rust, scab, or other diseases which cause shrunken kernels. These differences are undoubtedly due to differences in environmental conditions in the various states. A drought occurred in Kansas about heading time and thereafter which reduced the size both of heads and kernels but did not affect tillering.

No significant correlation was found between the number of heads per unit area and the weight of 1,000 kernels, and the correlations between number of heads and kernels per head were neither high nor very consistent. In the samples from Kansas there was a correlation

TABLE 2.—*Simple correlation coefficients of some plant characters influencing yield of wheat in 1926.*

Characters correlated	Oklahoma (winter) r	Oklahoma (winter) r/P. E.	Kansas (winter) r	Kansas (winter) r/P. E.	Nebraska (winter) r	Nebraska (winter) r/P. E.	Montana (winter) r	Montana (winter) r/P. E.	Montana (spring) r	Montana (spring) r/P. E.
Yield in grams per area and										
Number of heads.....	+.7158±.0508	14.1	+.6906±.0667	10.4	+.8233±.0228	36.1	+.6877±.0592	11.6	+.6624±.0434	15.3
Weight of 1,000 kernels	+.6518±.0599	10.9	+.5112±.0942	5.4	+.2400±.0666	3.6	+.4166±.0929	4.5	+.5657±.0526	10.8
Kernels per head.....	+.5380±.0740	7.3	+.8273±.0402	20.6	+.6253±.0431	14.5	+.8274±.0355	23.3	+.4459±.0620	7.2
Number of heads per unit area and										
Weight of 1,000 kernels	+.2014±.0999	2.0	+.0318±.1273	0.2	—.0415±.0706	0.6	+.2070±.1076	1.9	+.1584±.0754	2.1
Kernels per head.....	+.0293±.1040	0.3	+.3440±.1124	3.1	+.1887±.0682	2.8	+.2212±.1069	2.1	—.2538±.0724	3.5
Weight of 1,000 kernels and kernels per head.	+.2382±.0982	2.4	+.4239±.1046	4.1	+.2023±.0678	3.0	+.2486±.1055	2.4	+.1991±.0743	2.7

TABLE 3.—*Partial correlations and path coefficients for some plant characters influencing yield of wheat in 1926.*

Characters correlated[a]	Oklahoma (winter)	Kansas (winter)	Nebraska (winter)	Montana (winter)	Montana (spring)
	Partial Correlation Coefficients				
Yield and number of heads ($r_{YH.WK}$)	$+.9329 \pm .0135$	$+.8634 \pm .0324$	$+.9464 \pm .0074$	$+.9440 \pm .0122$	$+.9477 \pm .0079$
Yield and weight of 1,000 kernels ($r_{YW.HK}$)	$+.8676 \pm .0257$	$+.6613 \pm .0717$	$+.5766 \pm .0472$	$+.6240 \pm .0686$	$+.7990 \pm .0280$
Yield and number of kernels per head ($r_{YK.HW}$)	$+.8671 \pm .0258$	$+.8628 \pm .0326$	$+.8649 \pm .0178$	$+.9671 \pm .0073$	$+.9130 \pm .0129$
	Path Coefficients				
Yield and number of heads	0.6442	0.4947	0.7463	0.5078	0.7546
Yield and weight of 1,000 kernels	0.2730	0.2644	0.1804	0.1424	0.3325
Yield and number of kernels per head	0.5678	0.5450	0.4479	0.6800	0.5708

[a]Y = yield.
H = number of heads.
W = weight of 1,000 kernels.
K = number kernels per head.

TABLE 4.—*Multiple correlations between yield and the three characters number of heads, weight of 1,000 kernels, and number of kernels per head, 1926.*

	Oklahoma (winter)	Kansas (winter)	Nebraska (winter)	Montana (winter)	Montana (spring)
$R_{Y.HWK}$	0.9724 ± 0.0057	0.9631 ± 0.0092	0.9684 ± 0.0044	0.9853 ± 0.0033	0.9710 ± 0.0101
Percentage of total variability in yield caused by characters in question $100 \times [1-\sqrt{1-R^2}]$	76.68	73.09	75.06	82.91	76.08

of $+0.4239 \pm 0.1046$ between weight of 1,000 kernels and kernels per head, or in other words, plumpness and size of head. In that section soil moisture largely determined the yield and where moisture was deficient both heads and kernels were small.

To test further the relationship between yield and number of heads, weight of 1,000 kernels, and number of kernels per head, partial correlation coefficients were computed. For comparison path coefficients as suggested by Wright (4) also were determined. In Table 3 the partial correlations and path coefficients are presented for each state. A study of these data shows that the two methods of calculation bring out, in general, the same relations, although in varying degrees. The partial correlations show number of heads to have had the greatest influence on yield in Oklahoma, Nebraska, Montana (spring wheat), and possibly Kansas. Path coefficients indicate that number of heads had the greatest influence on yield in Oklahoma, Nebraska, and Montana (spring wheat). For Kansas the partial correlations between yield and number of heads and yield and number of kernels per head were nearly equal, although the path coefficient is higher for number of kernels per head than for number of heads. In general, weight of 1,000 kernels seemed to have the least influence on the variability of yield. This is very clearly brought out by the path coefficients. It would seem that the number of heads per unit area, or stand, had more influence on variability of yield than weight of 1,000 kernels or kernels per head.

In Table 4 are presented multiple correlation coefficients between yield and the three factors, number of heads, weight of 1,000 kernels, and number of kernels per head. If these three factors are the only ones determining yield as measured in this test, the multiple correlation coefficient should approach a value of 1. It will be seen that the values obtained range from 0.9631 to 0.9853, being no higher because of the methods of calculation. For each correlation is given, in percentage, the amount of total variability accounted for by the three characters in question. These values range from 73.09% to 82.91%.

CONCLUSION

From the data presented it would seem that under the cropping conditions in the fields sampled, number of heads per unit area was one of the most important factors in determining yield, closely followed by number of kernels per head or size of head. Plumpness of grain or weight of 1,000 kernels was not as important a factor in determining yield as the other two factors mentioned. It would follow that it is of great importance to obtain a good stand of wheat.

From the data presented it appears that there is little relationship between number of heads per area and size of heads or plumpness of grain, emphasizing the importance of full stands, and showing that thin seeding really does not increase the size of kernels.

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RESULTS FROM COOPERATIVE ROD-ROW WHEAT TRIALS IN 1927[1]

L. R. WALDRON[2]

In 1927 plans were made for 35 cooperative rod-row wheat trials variously located in North Dakota. Reliance was placed mainly upon Smith-Hughes instructors, but cooperation was obtained also with a few farmers and with certain state institutions including two substations. Out of the 35 planned experiments usable results were secured from 21. Lack of space prevents individual acknowledgment, but the writer wishes to thank those who carried out the experiments. Of course those who were faithful with no results deserve as much credit as those whose yields participated.

OBJECTS

The objects of the cooperative work were: (1) To secure comparative yield data (and other data) between certain named varieties of common wheat, some of which had been newly introduced; (2) to secure yield data between these named varieties and certain unnamed hybrid selections obtained from crosses made by the writer between the varieties Marquis and Kota; and (3) to secure yield data between the hybrid selections and the most important durum varieties grown in the state.

The objects of reporting these data in this article are: (1) To show the efficiency of results secured from volunteer cooperators in conducting rod-row wheat trials, and (2) to show the application of these results when applied to losses due to stem rust by a comparison of yields from resistant and non-resistant wheats.

PLAN

The trials consisted in the main of quadruplicated unguarded rod-rows, 10 varieties being used in most cases. The rows were planted 18 feet long to allow a net rod to be cut and on either side the entire plat was protected by two guard rows. At three points the experiments were planted in guarded triplicated rod-rows. The experiments were not distributed uniformly over the state, but the distribution was such that the state was divided into four regions, *viz.*, I, II, III, and IV, corresponding to the northeast, southeast, northwest, and southwest, respectively. Two trials, located geographically

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[2]Plant Breeder.

in region II, were assigned to region I due to soil similarities. There were six trials (with yields) in each of regions I and II, four in region III, and five in region IV.

The grain was cut by the cooperators and, when sufficiently dry, was shipped by express to Fargo where readings were made for stem rust, threshing was done, and yields and weights per bushel were secured. The cooperators took certain data but only those data taken at Fargo will be discussed here. One might question the value of these rod-row trials because of lack of guard rows for each yield row and because the cooperators were untrained in rod-row work. Calculations were made of probable errors by the mean deviation square method for all trials but one, in which case only duplicate plantings were finally available for yield purposes. The distribution of the probable errors for the 17 trials without protection rows is as follows:

Class centers, %	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10 5	11.5
Variates	3	7	2	2	0	1	1	0	0	1

The arithmetic mean of the above is 4.68%. The mean of the probable errors of the three trials with protection rows is 5.89% and the mean of the probable errors of six rod-row trials for different years at Fargo is 3.73%. The probable errors of the trials with unguarded rod-rows in most of the cases are not unduly high.

The comparative value of rod-row trials grown with and without guard rows is not discussed in this paper. The two averages given merely show that the absence of guard rows in this case had no tendency to increase the probable errors which have been secured. The lower probable errors at Fargo may be ascribed, perhaps, to the more uniform type of soil at Fargo than would be found in most of these experiments.

UNIFORMITY IN YIELD

If the experiments had been seriously affected by seasonal accidents or mistakes one would not expect uniformity in order of yield. Complete uniformity could not be looked for; but if, in several previous experiments, a number of wheats had been found to adhere to a certain order in yield, one might expect a similar order to obtain with the same wheats in experiments with environmental conditions somewhat similar to those of the first series. To test this, four wheats were taken, *viz.*, 1656.85, 1656.81, Ceres, and Marquis, which in other experiments have been yielding in the order indicated, Marquis yielding lowest. In 11 trials in eastern North Dakota, where these were grown, they were ranked in order of yield and the sums of

the ranks are 11, 25, 32, and 42. The expected sums are 11, 22, 33, and 44. The expected order was followed in nine cases. In one case 1656.81 and Ceres changed places and in another 1656.81 and Marquis changed places. These two series were compared, using the Chi-square test, which resulted in an X^2 value of 0.53. The value of P is thus 0.91, which indicates that in 91 cases out of 100 we should expect a fit as bad or worse than the one indicated if the data had been subjected to random sampling. The fit is thus seen to be very good indeed and approaches completeness. It is evident that so far as this criterion is applicable the outcome of the experiments may be considered satisfactory.

VARIETIES USED

The varieties used at any place consisted of four of the Marquis-Kota hybrid selections already mentioned, the new variety Ceres (also from a Marquis-Kota cross), Marquis, Garnet, and one or two durums. In addition, in regions I and II, Marquillo was used and in regions III and IV Reliance was in the trials. Two durums were used at all points except in region I where Quality was grown. At five places in regions I and II the new variety Hope was grown. The use of this variety was particularly interesting as it is essentially immune from stem rust.

Temperatures for the season were below normal and precipitation did not vary much from normal. Initial stem rust infections appeared later than has been the case for several years. In spite of low temperatures and time of initial infection considerable rust developed. Spring planting was later than usual which fact contributed to rust damage to some extent. A rust epidemic developed which proved to be rather serious.

Comparisons are possible between Marquis and Garnet for 19 localities. Yield, rust, and bushel weight averages were as follows:

	Yield, bushels	Bushel weight, pounds	Rust %
Garnet	25.5 ± 0.31	56.9	34
Marquis	23.7 ± 0.29	57.3	38

Garnet shows a significantly higher yield than Marquis, the difference being 1.7 ± 0.43 bushels. Bushel weights and rust percentages are essentially equal. It is not evident that Garnet wheat, which is earlier than Marquis, is inherently lower yielding because of its earliness.

COMPARISON OF VARIETIES WITH HYBRID SELECTIONS

RESULTS IN REGION I

For the six localities in region I averages on seven wheats were as follows:

Variety	Yield, bushels	Bushel weight, pounds	Rust %
1656.85	40.0±0.74	59.3	8
1656.84	35.2±0.65	57.4	16
1656.81	34.1±0.63	57.1	3
1656.83	33.7±0.63	57.4	15
Ceres	31.3±0.58	57.7	26
Marquillo	30.3±0.56	56.3	11
Marquis	25.7±0.52	55.7	58

Number 1656.85 shows an outstanding lead even over 1656.84. Ceres and 1656.85 differ by 8.7 ±0.94 bushels. The Dev./P. E. ratio here is relatively so large that a comparison is almost out of the question. Ceres has a lead over Marquis of 5.6 ±0.75 bushels. This excess of Ceres over Marquis of about 22% is not far from the average of many trials previously reported. In this instance the chances are above 2 million to 1 that the difference is of significance. Selection 1656.81 uniformly has carried less rust than the other selections shown. Only with an abundance of rust present does 1656.81 equal or surpass 1656.84 in yield. In no case has 1656.81 outyielded 1656.85. A comparison with durum is possible in only four cases in region I with yields and other averages compared with 1656.85 as follows:

Variety	Yield, bushels	Bushel weight, pounds	Rust %
Mindum	37.4±0.95	61.5	18
1656.85	34.4±0.87	58.8	6

The higher yield of Mindum lacks significance, but one notes the greater weight per bushel, which was true for each of the four places, in association with the greater amount of rust carried by Mindum.

RESULTS IN REGION II

Yields for only four wheats are available for all six localities. The data are as follows:

Variety	Yield, bushels	Bushel weight, pounds	Rust %
1656.85	40.9±0.81	60.8	3
1656.84	35.8±0.71	60.2	5
Marquillo	25.6±0.51	56.8	5
Marquis	23.2±0.46	57.7	39

One notes a striking similarity between the yields of these wheats and the same wheats in region I. Only Marquillo shows a really significant difference in yield. One notes a uniformly greater bushel weight which may be associated with the consistently lower rust readings for region II. The differences in rust readings are comparatively small.

In region II it is necessary to omit one experiment to bring Mindum into comparison. Doing this the averages were as follows:

Variety	Yield, bushels	Bushel weight, pounds	Rust %
1656.85	38.0±0.89	60.6	2
1656.84	32.4±0.76	60.0	4
Mindum	29.1±0.68	60.8	17
Marquillo	22.5±0.53	56.5	4
Marquis	22.0±0.51	57.3	36

The very marked reversal of position of Mindum relative to 1656.85 and even to 1656.84 is striking for the southeast section of the state in comparison with the northeast (region I). The contrast in weight per bushel between the two regions is striking for 1656.85 is relatively considerably heavier in region II.

The durum variety Nodak was also under trial in region II and its yield, in five experiments, was even farther below 1656.85 than was Mindum as is shown below:

Variety	Yield, bushels	Bushel weight, pounds	Rust %
1656.85	39.9±0.80	60.9	3
Nodak	28.1±0.56	58.4	1

This profound difference in yield of 11.8 ±0.98 bushels is obviously not due to variation in attack of rust. A marked difference is also noted in bushel weight. Considering both regions, 1656.85 shows a lead over Marquis of 16.0 ±0.64 bushels.

YIELDS OF HOPE IN EASTERN NORTH DAKOTA

Hope wheat, originated by E. S. McFadden of Webster, South Dakota, by crossing Marquis and emmer, has shown itself essentially immune from stem rust and evidently also from loose and stinking smut. It shows resistance to leaf rust. The behavior of this wheat under rust conditions is a matter of much interest. Averages of Hope and four other wheats grown at six localities in eastern North

Dakota in 1927, including Fargo in this instance, for yield and other data were as follows:

Variety	Yield, bushels	Bushel weight, pounds	Rust %
1656.85	40.5±0.81	60.2	2
1656.84	36.6±0.73	59.3	5
Hope	33.0±0.66	57.3	0
Ceres	31.0±0.62	59.2	9
Marquis	24.7±0.50	58.2	41

Freedom from rust on Hope is evidently the deciding factor in yield between it and Marquis. The comparatively small amount of rust on Ceres has probably affected the yield of that variety. It was not observed that Hope was injuriously affected by diseases other than rusts and smuts, although it is known to be susceptible to black chaff and probably also to root rot. Further experiments are needed to determine if Hope wheat is inherently lower yielding than certain of the better rust-resistant Marquis-Kota hybrids, such as 1656.85. One notes that the bushel weight of Hope is less even than that of Marquis.

YIELDS IN REGION III

Results from only four localities are available from the northwestern area of the state. Averages of yields, bushel weights, and rust were as follows:

Variety	Yield, bushels	Bushel weight, pounds	Rust %
1656.84	20.0±0.71	59.5	2
1656.85	19.9±0.71	59.5	2
Ceres	19.8±0.70	60.1	6
1656.83	19.7±0.70	58.3	2
Garnet	18.4±0.65	59.3	20
Reliance	18.1±0.64	58.6	22
1656.109	17.5±0.62	60.3	2
Marquis	17.1±0.61	58.4	21

One notes a remarkable change in disparity of yield when this region is compared with regions I and II, and associated with this is the decreased amount of rust carried by Marquis and Garnet. Marquis is barely significantly lower yielding than 1656.84.

There are data from only three localities with durums entering into the comparison. The following averages were for the important wheats:

Variety	Yield, bushels	Bushel weight, pounds	Rust %
Mindum	25.8±0.81	63.8	2
1656.84	23.9±0.75	59.3	2
1656.85	23.8±0.75	59.7	2
Nodak	22.8±0.72	61.7	Trace
Ceres	22.8±0.72	60.3	6
Garnet	20.6±0.65	59.0	19
Marquis	19.3±0.61	58.7	19

YIELDS IN REGION IV

Results from five localities are available from this region. The selection 1656.85 was grown only at three places, 1656.97 being at the other two. In this discussion the five yields are considered as a unit. Averages for the five localities were as follows:

Variety	Yield, bushels	Bushel weight, pounds	Rust %
Mondak	30.7±0.88	59.9	11
1656.85	27.4±0.79	59.8	4
Nodak	27.2±0.78	59.5	1
1656.84	26.3±0.75	59.8	7
1656.109	26.2±0.75	60.7	8
Ceres	25.4±0.73	59.7	14
1656.83	25.3±0.73	58.7	6
Reliance	22.1±0.63	58.4	37
Garnet	20.3±0.58	58.0	23
Marquis	19.6±0.56	56.5	35

Rust infection is not much greater than in region III, but the difference in yield between Marquis and 1656.85 in region IV is 7.8 ±0.97 bushels as compared with a difference of 2.8 ±0.94 bushels for region III. Perhaps in the more southern district the rust fungus became a more efficient parasite with the higher temperatures prevailing, which efficiency was reflected only in part by an increase in the visible lesions. Mondak and Nodak are two selections made by R. W. Smith out of Kubanka. Mondak outyields Nodak 3.5 ± 1.18 bushels in the face of lesser rust resistance.

ESTIMATE OF LOSSES

It is evident from the foregoing data that rust caused serious losses in 1927 to varieties susceptible to the disease. It should be possible to arrive at some estimate of these losses from the foregoing yields, but before doing this losses from other causes than rust will be considered. Such losses in 1927 were due mainly to weather conditions. As 1656.85 seemed to suffer but little rust injury, and as it was grown

at all localities except two in region IV for which a satisfactory substitute was used, it may be used to measure such losses. This selection yielded practically the same in regions I and II, and if rust damage to 1656.85 was negligible in those two regions, the conclusion seems tenable that the yielding capacity of the two regions for 1656.85 was essentially the same so far as the two sets of trials were representative of the two regions.

When regions I and II are compared with region III, one finds a marked difference with an approximate decrease of 20.6 bushels or 50.9% because of factors other than rust. Similarly, region IV shows a falling off from regions I and II of 13.1 bushels or 32.3%. Comparing regions IV and III, similar figures are 7.5 bushels or 27.4%.

An estimation of rust losses in any district has meaning if the variety commonly grown is susceptible to the disease and if there exists another variety resistant to the disease which can be used as a basis for comparison. To make the results reliable the two wheats should possess similar yielding capacities in absence of rust, and their reactions to diseases other than rust should not differ greatly. Data are meager in regard to the natural yielding capacity of Marquis and 1656.85 in absence of stem rust, but certain experiments in the trials at hand help out. At one locality in region II and at four in region III rust readings were relatively low for Marquis and absolutely for 1656.85. The averages for the five localities were as follows:

Variety	Yield, bushels	Bushel weight, pounds	Rust %
1656.85	19.9 ± 0.49	59.6	1
Marquis	17.5 ± 0.43	58.5	19

The lead of 1656.85 over Marquis is 2.4 ±0.65 bushels which is of some significance, the Dev./P. E. value being 3.7. But Marquis had 19% rust which must be considered. With this small difference in yield, in the presence of 19% rust on Marquis, an assumption of approximate equality of yield under rust-free conditions, with the climatic conditions to which they were subject, seems reasonable.

Besides this particular comparison, one notes a general sweep through the data of a lessened disparity of yield between 1656.85 and Marquis as the amount of rust decreases. This appears as one studies the four regions as they have been presented, but it shows still better if the two localities geographically belonging to region II are averaged with the other localities of that region rather than with region I as has been done earlier in this paper.

Mention has already been made of the illogical treatment of these two localities as to their geography, this treatment being accorded because of soil similarities. The two localities, Buffalo and Arthur, are located in Cass County west and northwest of Fargo. With this rearrangement the averages of 1656.85 and Marquis for the three characters yield, bushel weight, and rust for the four regions are shown in Table 1.

TABLE 1.—*Averages of 1656.85 and Marquis rearranged according to geographical locations to show the correlation of yield differences between the two wheats with a decrease of rust.*

Region	Yield per acre, bushels			Bushel weight, pounds		Rust, %	
	1656.85	Marquis	Diff.	1656.85	Marquis	1656.85	Marquis
II.......	38.9	21.3	17.6	60.6	56.3	6	51
I.......	43.7	30.8	12.9	59.0	57.4	5	45
IV......	27.4	19.6	7.8	59.8	56.5	4	35
III......	19.9	17.1	2.8	59.5	58.4	2	21

The data in Table 1 indicate very well the reduction in spread of yields between 1656.85 and Marquis as one proceeds from regions of greater to lesser amounts of rust. If the yield differences and the rust of Marquis in percentage be distributed upon X, Y axes, the locus of the points is nearly a straight line, and if an extrapolation were attempted one would find the difference in yield between 1656.85 and Marquis to have a zero value with Marquis still carrying 10% or more of rust. The natural implication of this is that with strictly zero rust Marquis would outyield 1656.85, but this matter should be left to experimental trials. Aside from stem rust Marquis is inclined to be rather resistant to disease and this fact does not lessen the reasonableness of the comparison here instituted. Assuming an essential equality of yield between the two and using yields and differences of yields shown in Table 1, the percentage losses due to stem rust for the four regions is calculated to be as follows:

Region	Rust loss %
I..............................	29.52
II..............................	45.24
III..............................	14.07
IV..............................	28.46

One notes that the maximum rust loss of any region is less than the maximum non-rust loss when regions are compared with each other. Regions I and II were considered equal to each other with regard to non-rust factors. If the data as arranged in Table 1 are

used, 1656.85 shows a little falling off in yield in region II compared with region I.

With these percentages at hand a further step was taken in an effort to measure the actual bushel loss of common wheat in North Dakota because of rust and further to arrive at a single percentage to express this loss. Data from the U. S. Department of Agriculture are available for the 1925 census determination of the total wheat acreage of the state by counties, for the percentage of the total wheat acreage in common wheat, and for the estimated yields of common wheat by counties for 1927. The calculated loss of common wheat is shown in Table 2.

TABLE 2.—*Estimated loss of common wheat in North Dakota in 1927 due to stem rust calculated by comparing yields of two wheats, one susceptible and one resistant.*

Region	Acreage %	Estimated 1927 production, bushels (000)	Hypothetical production, bushels (000)	Loss due to rust, bushels (000)
I	14.3	8,143	11,553	3,410
II.	19.9	16,468	19,116	8,648
III	28.8	19,349	22,517	3,168
IV.	37.0	27,657	38,660	11,003
Totals	100.0	65,617	91,846	26,229

From Table 2 the calculated loss of common wheat is seen to be approximately 26 million bushels or 28.6%. This estimated loss is considerably larger than other estimates which have appeared, but it seems to be the only one based on comparative yields. This estimate would be subject to correction if more data were available. More comparative trials would have measured the losses for the state with greater accuracy and the comparisons available are not as well distributed as they might be. One notes from the table that regions III and IV contain about two-thirds of the common wheat acreage. These regions showed the lesser amounts of rust loss from the experimental data. This calculation assumes that the percentage loss upon the farms, due to rust, would be essentially the same as that exhibited in these experiments. This assumption seems a reasonable one, although actual data upon this point are meager. One error is involved in the assumption that the common wheat of the state is all as susceptible as Marquis. This is not true with regard to Kota, of which there is an appreciable acreage. In this calculation of rust loss it is likely that certain errors would be offset by others. With all its defects, the result given has the merit of being based upon quantitative methods.

SUMMARY

1. This paper reports 1927 results from 21 cooperative rod-row wheat trials variously located in North Dakota and also furnishes an estimate of 1927 common wheat rust losses in the state.

2. Judged by the size of the probable errors, by the rank in yield of certain wheats in comparison to what was expected of them from their previous behavior, and judged by the general consistency of the results among themselves, the outcome of these rod-row trials is considered satisfactory.

3. From 19 comparisons Garnet outyielded Marquis by a significant amount.

4. In regions I and II, in eastern North Dakota, the rust-resistant hybrid selection 1656.85 significantly outyielded all wheats except that in region I it was outyielded by Mindum (a durum) but not significantly. The excess of yield of 1656.85 over Marquis for 12 localities in the eastern section of the state was 16.0 ±0.64 bushels.

5. Six comparisons in eastern North Dakota between the essentially immune variety Hope and other wheats show that it yields significantly more than Marquis, not signifiantly different from Ceres, and significantly less than 1656.84 and 1656.85. Hope stands nearly midway between Marquis and 1656.85.

6. In western North Dakota, with less rust, 1656.85 showed less advantage over Marquis than it did farther east.

7. Judging by the behavior of 1656.85 from region to region and by Marquis and 1656.85 in the four regions, factors other than rust brought about losses equal to or surpassing losses due to rust.

8. An estimate based on available acreage and yield statistics indicated a loss to common wheat in North Dakota in 1927 of 28.6% which is equal to approximately 26 million bushels.

CELLULOSE DECOMPOSITION PRODUCTS AS SOURCES OF ENERGY FOR AZOTOBACTER AND *B. AMYLOBACTER*[1]

P. G. Krishna[2]

Nitrogen-fixing organisms are present in most normal soils, but their activities in the soil are dependent on the available energy-furnishing material. It seems quite logical that in soil the only source of energy-furnishing material must be the decomposition products of plant residues, such as stubble, roots, leaves, etc., all of which contain a high percentage of cellulose. These cellulose materials are not directly attacked and decomposed by the nitrogen-fixing organisms.

McBeth (6)[3] working with cellulose in the form of ground filter paper and using *Bac. rossica*, *Bac. fimi*, and *Bac. flavigana* for breaking down the cellulose and with *Azotobacter chroococcum* as the nitrogen-fixing agent reported that the latter utilized the decomposition products of the cellulose material as sources of energy for nitrogen fixation.

Lohnis and Green (5) reported that the nitrogen fixed by *A. chroococcum* in 100 cc of mannite media was doubled when fresh straw was added. Hunter (2) found no increase in the amounts of nitrogen fixed when straw was added to the media. Dvorak (1) and Hutchinson (3) have shown that plant residues are utilized by Azotobacter for nitrogen fixation.

In the present investigation it was intended to observe the utilization of cellulose decomposition products by Azotobacter and *B. amylobacter* for nitrogen fixation.

METHODS

The Kjeldahl method was employed for total nitrogen determinations. Coarsely ground filter paper and straw were used as cellulose materials.

Two soils, a loam and a sand, and Ashby's nitrogen-free media were employed in these experiments.

In experiment I, to 100-gram portions of a loam soil in 250-cc Erlenmeyer flasks was added 1 gram of coarsely ground filter paper

[1]Part of a thesis submitted to the Faculty of the Graduate School at Cornell University in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication November 25, 1927.

[2]The author, who is now located at Picket Secunderabad (Deccan), India, wishes to express his indebtedness to Dr. S. A. Waksman at whose suggestion this problem was taken up and to Dr. J. K. Wilson for criticism and encouragement.

[3]Reference by number is to "Literature Cited," p. 514.

and the varying treatments as shown in Table 1. The flasks were incubated for four weeks. In this experiment the flasks with the soil were not sterilized. The soil in the flasks was kept at an optimum moisture content throughout the course of the incubation period, after which the soil was dried and 5-gram samples used for the determination of total nitrogen.

DISCUSSION OF RESULTS

In experiment I it was observed that at the end of the incubation period quite a large amount of the cellulose was left undecomposed. It is evident from Table 1 that there was no increase in total nitrogen. Even the flasks receiving 20 mgs of ammonium nitrate did not show

TABLE 1.—*Utilization of cellulose decomposition products by nitrogen-fixing organisms, experiment I.*[a]

Flask No.	Treatment	Mgs total N per 5 grams soil	Mgs fixed N
1	Control	2.76	——
2	Trichoderma	2.86	0.12
3	*A. vinlandii*	2.96	0.20
4	Trichoderma and *A. vinlandii*	2.88	0.12
5	Trichoderma + 20 mgs $(NH_4)NO_3$	3.56	0.80
6	Trichoderma + *A. vinlandii* + 20 mgs $(NH_4)NO_3$	3.42	0.66
7	*A. vinlandii* + 1 gram mannite	3.29	0.53
8	Trichoderma + *A. vinlandii* + 1 gram mannite	3.25	0.49
9	Trichoderma + 1 gram mannite	3.32	0.56

[a]All figures are averages of duplicates.

any appreciable increase in the amounts of nitrogen fixed. All soils which received mannite showed quite appreciable gains in the amounts of nitrogen fixed. This was to be expected as the nitrogen-fixing organisms in the soil would be activated due to the presence of an available source of energy. In the flasks receiving 1 gram of mannite there was fixed from 9 to 11 mgs of nitrogen, irrespective of the treatment. It may be concluded that cellulose in the form of ground filter paper did not furnish available energy material through its decomposition for the nitrogen-fixing organisms.

In experiment II, to 100 cc of Ashby's media in 250-cc Erlenmeyer flasks was added 1 gram of coarsely ground straw and the flasks sterilized. To the cooled flasks were added the suspensions of the organisms as indicated in Table 2, and the flasks incubated for four weeks. Total nitrogen was determined after the incubation period.

In experiment III a sandy soil was used. The same procedure was adopted as in the previous experiment. An optimum moisture content was maintained throughout the course of the experiment.

After the incubation period 5 grams of the soil were used for the determination of total nitrogen. The *B. amylobacter* culture used in this experiment was found to be an active nitrogen fixer. This culture (4) was shown to fix about 5 mgs of nitrogen per gram of

TABLE 2.—*Utilization of cellulose decomposition products by nitrogen-fixing organisms.*[a]

Flask No.[b]	Treatment	Experiment II In liquid culture Mgs total N	Mgs fixed N	Experiment III In sand culture Mgs N in 5 grams soil	Mgs fixed N
1	Control	17.50	——	2.59	——
2	Trichoderma	17.57	0.07	2.73	0.14
3	Cellulose bacteria	17.36	—0.14	2.80	0.21
4	Trichoderma and Amylobacter	19.25	1.75	3.15	0.56
5	Trichoderma and Azotobacter	17.50	0	3.15	0.56
6	Cellulose bacteria and Amylobacter	18.62	1.12	3.57	0.98
7	Cellulose bacteria and Azotobacter	17.57	0.07	3.22	0.63
8	Cellulose bacteria, Azotobacter, and Amylobacter	18.76	1.26	3.71	1.12
9	Trichoderma, Azotobacter, and Amylobacter	18.27	0.77	3.08	0.49

[a]All figures given are averages of duplicates.

[b]All received 1 gram of coarsely ground straw, crude cultures of Amylobacter and the cellulose-decomposing bacteria were used.

dextrose disappearing from the media. Trichoderma and the cellulose decomposing bacterial cultures used in these experiments were found to decompose cellulose vigorously.

It was observed at the end of the incubation period that more of the straw was decomposed in the sandy medium than in the liquid media.

It is evident from these experiments that straw, through its decomposition, furnished energy material for the nitrogen-fixing organisms. It is known that there are hosts of organisms in the soil which attack and decompose the plant residues readily. Hence, it seems very probable that the nitrogen-fixing organisms derive their energy material through the decomposition of the plant residues by other organisms.

In both of these experiments *B. amylobacter* seems to have utilized the decomposition products arising through the decomposition of straw more efficiently than the Azotobacter. In the liquid cultures Azotobacter did not seem to have utilized any of these products; while *B. amylobacter* showed increases in the amounts of nitrogen

fixed, indicating its ability to use these products for the needed energy.

The results in experiment III are more convincing than those of experiment II. In the sand cultures Azotobacter seems to have utilized these products to some extent. Even here *B. amylobacter* is seen to be able to utilize these products better than Azotobacter, as indicated by the amounts of nitrogen fixed. It may also be noticed that *B. amylobacter*, accompanied by the cellulose-decomposing bacteria, utilized these products more efficiently than when accompanied by Trichoderma. This might indicate that products arising through the decomposition of cellulose by the bacterial cultures are more readily utilized by *B. amylobacter* than the products which resulted through the activities of Trichoderma. Azotobacter does not seem to be partial in this respect, as it seemed to utilize the decomposition products resulting through the activities of both these organisms to about the same extent.

SUMMARY

Cellulose in the form of ground filter paper did not furnish the energy material through its decomposition to Azotobacter in pure cultures.

Straw furnished the needed energy material, through its decomposition to both Azotobacter and *B. amylobacter*.

B. Amylobacter when accompanied by cellulose-decomposing bacteria fixed more nitrogen than when accompanied by Trichoderma.

B. amylobacter utilizes these decomposition products more efficiently than Azotobacter.

Nitrogen-fixing organisms are dependent upon other micro-organisms for breaking down the cellulose material into available carbohydrates which they can utilize.

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SOIL REACTION AND NITROGEN FIXATION[1]

P. G. Krishna[2]

It is known that the reaction of the medium determines the organisms that are responsible for nitrogen fixation. Gainey (4)[3] conclusively demonstrated that Azotobacter is absent in soils with reactions below pH 6.0. Batchelor and Gainey (2) and Johnson and Lipman (5) showed that the limiting reaction for Azotobacter was between pH 5.9 and 6.0. Other bacteria, such as *B. mesentericus*, *B. pneumoniae*, *B. lactis viscosus*, *B. radiobacter*, *B. prodigiosus*, and *B. asterosporus*, are reported to fix small quantities of nitrogen.

In soils with reactions below pH 6.0, *B. amylobacter*, *Clostridium pasteurianum*, and other bacteria are shown to be active in the nitrogen fixation process (6).

It was intended to observe the influence of soil reaction on nitrogen fixation and to observe the correlation between soil reaction and its ability to fix atmospheric nitrogen through bacteria.

For this study some soils were obtained from the experimental plats of the Agronomy Department at Cornell University. The treatments applied, the crops grown, and the soil reactions for the several plats are given in Table 1.

Table 1.—*Plat treatment and soil reaction.*

Plat No.	pH	Treatment	Crop
752	7.65	Lime, superphosphate (acid phosphate), KCl	Vetch, corn, oats
Triangle 1	7.55	Lime, superphosphate (acid phosphate), KCl, $NaNO_3$	Hay and clover
3610	7.33	No lime	Orchard grass
Triangle 2	7.15	Lime, superphosphate (acid phosphate), KCl, $NaNO_3$	Hay and clover
3611	7.03	Lime, leather meal, KCl	Orchard grass and alfalfa
729	5.9	No treatment	No crop
755	5.22	No treatment	Vetch, corn, oats
3608.5	6.60	Leather meal, $NaNO_3$	Alfalfa (good stand)
3608.4	6.31	Leather meal, $NaNO_3$	Alfalfa (fair stand)
3608.3	5.89	Leather meal, $NaNO_3$	Alfalfa (plants small and very poor stand)
3608.2	5.825	Leather meal, $NaNO_3$	Alfalfa (only few plants)
3608.1	5.78	Leather meal, $NaNO_3$	Alfalfa (few scattered plants)

[1]Part of a thesis presented to the Faculty of the Graduate School at Cornell University in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication November 25, 1927.

[2]Located at Picket Secunderabad (Deccan), India.

[3]Reference by number is to "Literature Cited," p. 518.

Five samples were taken from plat 3608 about 3 feet apart. It was noticed that the alfalfa had almost disappeared from the most acid parts (pH 5.89 to 5.78), leaving a sharp line of demarkation where alfalfa was growing and where it was disappearing.

METHODS

Ashby's (1) nitrogen-free media was used for the nitrogen fixation. To 100 cc of the media in 250-cc Erlenmeyer flasks 0.5 gram of the soil samples was added and the flasks incubated for two weeks. At the beginning of the incubation period dextrose and total nitrogen contents were determined in two flasks with each of these soil samples to serve as checks. The pH, dextrose, and total nitrogen were determined in all the flasks at the end of the incubation period and the results are recorded in Table 2.

TABLE 2.—*Influence of soil reaction on nitrogen fixation.*

Plat No.	pH of soil	Numbers of bacteria in millions[a]	Mgs dextrose disappeared[b]	Mgs nitrogen fixed[b]	Mgs nitrogen fixed per gram dextrose disappeared	Final pH of media
752	7.65	11.8	894	3.67	4.1	4.0
Triangle 1	7.55	11.5	918	3.57	3.8	4.0
3610	7.33	11.2	900	3.60	4.0	4.0
Triangle 2	7.15	9.0	925	4.38	4.7	4.0
3611	7.03	10.1	900	4.03	4.4	4.0
3608.5	6.60	13.2	895	3.26	3.7	4.0
3608.4	6.31	14.0	894	3.32	3.7	4.0
729	5.9	12.0	775	2.73	3.6	3.6
3608.3	5.89	16.5	907	2.73	3.0	4.0
3608.2	5.825	9.8	892	2.69	3.0	4.0
3608.1	5.78	8.4	906	2.84	3.1	4.0
755	5.22	7.4	925	2.69	2.9	4.2

[a]Average of three plates.
[b]Averages of duplicates.

Bertrand's method was employed for the determination of the dextrose. The Kjeldahl method was used for total nitrogen determinations.

Biilmann's (3) quinhydrone electrode method was used for the determination of the pH of the soils; and the colorimetric method was used for the determination of the final reaction of the media.

Beef extract-peptone agar was used for the bacterial cultures. This media is not suitable for growth of Azotobacter. Anaerobes would not grow under the aerobic conditions, so that the numbers reported are for the aerobes able to grow well on this media.

DISCUSSION OF RESULTS

It is evident from Table 2 that there is a very good correlation between the reaction of the soils and nitrogen fixation, irrespective of the treatments accorded or of the crops grown. There is a progressive increase in nitrogen fixation with decreasing acidity of the soil. This is clearly shown in Fig. 1. The largest amounts of nitrogen were fixed in soils with a reaction between pH 7.0 and 7.4.

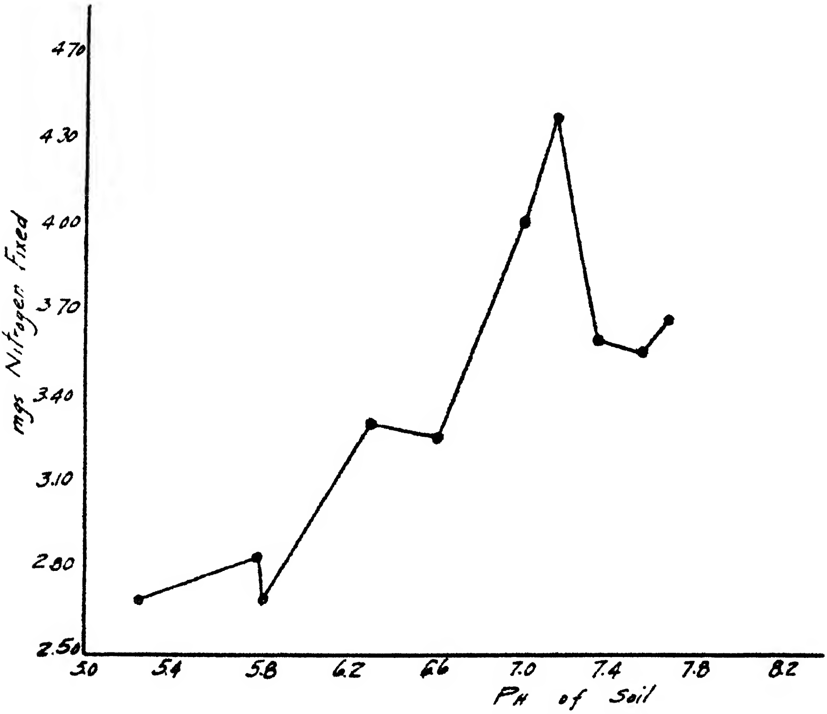

FIG. 1.—Influence of soil reaction on nitrogen fixation.

It is interesting to note that soils with a reaction between pH 5.2 and 5.9 fixed about three mgs of nitrogen per gram of dextrose disappearing from the media, while 3.6 mgs of nitrogen were fixed in soils with reactions between 5.9 and 7.0, and 4 or more mgs in soils with reactions over pH 7.0. It was shown that Azotobacter is not present (4) in soils with reactions below pH 6.0. The nitrogen fixed in soils with reactions between 5.2 and 5.9 must be due to organisms other than Azotobacter.

It is also observed that there is no relation whatsoever between the numbers of bacteria and the reaction of the soils or the nitrogen fixation, or between the reaction of the soil and the disappearance of the dextrose in the media.

During the season of 1926, corn was grown on plats 729, 752, and 755. The amounts of corn fodder produced were as follows:

Plat No.	pH	Pounds of fodder	Mgs N fixed per gram dextrose disappeared
729	5.9	12,450	3.6
752	7.65	19,600	4.1
755	5.2	18,200	2.9

Although it is not justifiable to draw any conclusions from these few data, it may be pointed out that there does not seem to be any correlation between the nitrogen-fixation and the crop-producing ability of the soil. Nitrogen fixation was about the lowest in case of plat 755, but 5,750 more pounds of fodder were produced on this plat than on plat 729 where nitrogen fixation was much greater.

SUMMARY

Confirming the results obtained by other investigators, these observations show a very good correlation between the reaction of the soils and their nitrogen fixation.

There was a progressive increase in the amounts of nitrogen fixed with decreasing acidity of the soils. About 3.0 mgs of nitrogen were fixed by soils with reactions between pH 5.2 and 5.9, while between 3.6 and 4.7 mgs of nitrogen were fixed in soils with reactions between pH 5.9 and 7.65.

There was no correlation between numbers of bacteria and nitrogen fixation, between bacterial numbers and soil reaction, or between the soil reaction and the disappearance of dextrose.

The soil reaction is the dominant factor influencing nitrogen fixation in soils.

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CRITICISM OF THE REPORT OF THE COMMITTEE ON AGRONOMIC TERMINOLOGY[1]

KARL F. KELLERMAN[2]

I hope I shall not be the only member of the American Society of Agronomy to record the fact that the Society is not unanimous in approving the report of the Committee on Agronomic Terminology presented at the meeting of November 17, 1927, entitled "Median Terms in Adjectives of Comparison."

Even cursory examination of this report raises many questions as to the desirability of the suggested language-building.

The Committee may, perhaps, have contributed a useful service in making strikingly apparent to others besides writers dealing with technical descriptions the fact that the English language is curiously deficient in specific terms to signify the state more or less half way between the extremes for which words usually exist. For example, "short" and "tall," "low" and "high," convey more or less clear impressions of extremes of stature or altitude, but the words "average, medium, normal,"etc., must be linked to the idea of stature or altitude in order to inform the auditor or reader of the idea under consideration.

Surprisingly, if one had never thought of it before, other national languages and even the international language Esperanto are also curiously deficient in these median terms. Is it not reasonable under the circumstances to assume that, for the past generations at least, human needs have not developed in such a way as to require the wealth of vocabulary for median terms which up to the present has become established for the extremes?

For technical writers a more brief phraseology for designating the median or intermediate states may be desirable, although even here serious doubts exist. Since the Committee is reporting to agronomists, but points out the need of new terms only for "genetic and breeding papers" and for "geology, edaphology, physics, and astronomy," is it not a fair challenge to ask which branch or branches of science brought to the Committee pleas for the creating and establishment of median adjectives?

Specific consideration of the plan of the Committee at the outset runs afoul of their defense of the combination of the prefix "mid"

[1]Received for publication March 12, 1928. The report in question appears on pages 182 to 191 of this volume of the JOURNAL.

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with a noun for the type of the new median adjective. The diagram (Fig. 1) cited as a definite test for the accuracy or propriety for the creation of the median adjective "midheight" is certainly neither mathematical nor biometrical. Apparently its conclusiveness must be taken on faith, unless one is so unkind as to apply the teachings of the texts upon elementary logic; the diagram then becomes familiar as a type of the faulty syllogism.[3]

It should be noted, furthermore, that the attempt to establish a different connotation for "midhigh" when spelled "midheight" is not supported by anything easily discoverable in books of synonyms, dictionaries, or rhetorics. Since the Committee has merely created a new adjective (most unfortunately in nounal form although the adjectival form also is to be employed) and is also forced to create arbitrarily a new meaning for each, it would have been far less confusing if the arbitrary action of the Committee had been more frankly so and if this and other new words had been created without the apparent semblance of resuscitation of Shakespearian or classical forms.

As a matter of fact, the more obvious construction of words by main strength occurs somewhat later in the Committee's report. I refer prticularly to the word "umblux" and its median "mid-umblux." Some attempt, even here, to give this word a classical derivation is made by explaining that the "umb" is from "umbra." I might point out equally valid claims for "umbo" or other words happening to use these three letters. For convenience in tabular use the Committee might as properly have still further abbreviated "umblux" possibly to "mux," and "midumblux" to "midux." No warrant for dismembering words and using certain of their letters in creating other words exists from either the Latinist's or the litterateur's point of view. To be more specific, "umb" is not the root of "umbra" and "umblux" is as frankly a created word as if it were invented by some advertising manager to designate a new soap or a new powder.

It might perhaps be argued that the report of the Committee is peculiar only because of the great number of unusual suggestions made, but that in principle it did less violence to the English language than frequently occurs in different branches of science, for example, the introduction of pH, F_1, etc. There is, however, a convincing argument that can be very properly raised in answer.

[3]For example: Major premise: Low and high are the extremes.
Minor premise: Midheight can be used as the median term.
Conclusion: Any other word would be incorrect as the median.

Mathematical, chemical, and the newer genetic symbols are frankly technical symbols, designed to facilitate highly technical writing and accomplishing a precison together with a brevity highly desirable in technical publications.

The multiplication of words urged in the Committee report obviously will accomplish none of these desiderata. Unless new words materially improve the possibility and probability of precise expression or in other ways benefit the literary development as well as the technical accuracy of the language, it is at least doubtful whether their creation is praiseworthy.

I wish to state clearly and emphatically that I have no fundamental objection to the coining of words, even if many are coined at once. The few essentials which I believe must be kept in mind by the verbal minters are (1) the need for a new word, (2) its exact meaning, and (3) its probable suitability for its proposed use.

This raises one phase of the scope of the Committee's work which appears to have been overlooked. Much of the alleged confusion in the simultaneous consideration of several factors to which the Committee has referred as their reason for creating medians would be eliminated by a clarification in the use of the terms discussed, that is, by developing discriminating definitions. Instead the Committee proposes the complication of the existing confusion by establishing but a single median term for qualities or factors expressed by several more or less overlapping synonyms, but without furnishing definitions or discriminations of any sort whatever.

Without attempting detailed discussion of the tables of the Committee report, perhaps enough has been said to bring out the vagueness of the connotation of the new words and the probable confusion if any attempt should be made to employ them as shifting intermediates for groups of words occasionally synonymous but occasionally having shades of meaning not indicated in the tabular outlines. Writers employing the new vocabulary would be more likely to furnish food for the cartoonist and the vaudeville humorist than to add materially to the clarity of scientific papers.

Of the so-called basic terms proposed by the Committee, I shall comment upon but one additional specimen. According to Webster's New International Dictionary, "stouth" means a store or hoard and also stealth or theft. I quote from the Committee's tabulation "slender-midstouth-stout." Does not the Committee owe us a definition, an explanation, or something? Can it be that the use of "stouth" was an act of desperation forced by the obvious impracticability of defending the use of "midstoutness" as a median adjec-

tive? Such use would have placed before us a new median adjective, not exactly analogous to midheight, being a noun created by attaching a nounal ending to the original and hitherto adequate adjective.

For amusement let us carry the hypothetical example a little further: (*Lean, midstoutness, stout.*) *The midstoutness hog had received a balanced ration.* The substitution of the Committee's word "midstouth" for " midstoutness" may conceal the absurdity of this statement, but actually the substitution will make the sentence even more bewildering and bizarre.

I have neither space nor inclination to review the new or unusual basic terms in detail, but in general I believe it will be difficult to disprove my claim that they are unnecessary for the preparation of clear and concise statements relating in any way to agronomy.

COMMENT ON DR. KELLERMAN'S CRITICISM OF THE COMMITTEE REPORT ON "MEDIAN TERMS"[1]

CARLETON R. BALL[2]

The foregoing paper represents the third successive draft submitted by its author. The second draft was much more temperate in its language than the first. In this third draft several of the positions held in the first and second drafts have been completely abandoned, including two proposed substitute methods of designating intermediates. The remaining discussion seems to warrant the following comments:

1. The Committee is not called upon to defend either its entry into constructive philology, or its methods. It recognized a need and offered a remedy. It has suggested and explained a logical and satisfactory method of forming the proposed median adjectives. There is no compulsion in their use. Final acceptance always must rest with the individual.

2. The challenge concerning other "branches of science" is accepted. The Committee went outside the strict field of agronomy (crops and soils) purposely and properly. In his writings the agronomist must use mathematics, chemistry, and physics, and many of their applications, such as botany, geology, meteorology, and engineering. The Committee desired, furthermore, to interest the whole scientific fraternity in the proposal.

3. The diagram presented in Fig. 1 of the Committee's report chiefly is philological, relating to the branch of knowledge under consideration. It is mathematical to the extent of correctly fractioning a series. It shows clearly the distinction between "midlow" and " midhigh," respectively, and "midheight."

4. If the Committee was "most unfortunate" in creating its new median adjectives in the form of nouns, it had plenty of good company. What is the particular difference in form between "midheight," when used as an adjective modifying "plants," and the hundreds of other nouns in every-day use as adjectives? Consider, for instance, "middistance" runner, "middleweight" champion, "midday" meal, "midnight" ride (of Paul Revere), "midwest" farmer, "midsummer" heat, "midwinter" festival, "middleclass" people, or "midseason" oats, the latter published repeatedly by the Bureau of which the

[1]Received for pnblication April 9, 1928.

[2]Chairman, Committee on Terminology, American Society of Agronomy, and Senior Agronomist in Charge, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.

writer of the criticism is Associate Chief. Forgetting the prefix "mid" temporarily, what shall we do about the abundant use of adjectives in nounal form in such combinations as "apartment" house, "air" line, "barometer" reading, "citrus" fruit, "color" scheme, "fur" seal, "mercury" column, "newspaper" clipping, "pig" club, "plant" disease, "rust" infection, "soil" bacteria, or "tire" gauge? The critic himself says "noun form" instead of "nounal form," although the latter is an adjectival form equally available.

5. Creation, by "main strength," of "umblux" and similar words is deplored by the Committee's critic. No attempt was made "to give this word a classical derivation." The pedagogic principle of teaching the new by reference to the old was heeded. "Umbra" and "lux" were the "old" for the classicist, and "umbrella" was the "old" for the non-classicist. Word analysis usually has been regarded as a helpful and even a fascinating study. As a matter of fact, is there anything really the matter with "umblux" as a word? Is it less attractive or more difficult than our homely word "umbrella?" Shall we cast out "anthrax" and "hollyhock" from the language because they may be less euphonious than some other words? Why should not a word be "frankly created?" Are not the words "ampere," "electron," "watt," and many others in technical or popular use frankly created words? In fact, are not all the words in any language matters of creation at some time?

6. How does it come that, "No warrant for dismembering words and using certain of their letters in creating other words exists?" The term "chevon," as a name for goat meat was created by "dismembering "*chevre* (French for goat) and *mouton* (French for mutton) and "using certain of their letters." It was devised by commercial agencies and appears in a recent publication of the U. S. Department of Agriculture (Farmers' Bulletin 1203.10, revised 1926). It is by no means the only instance of its kind. Scientists in the Bureau of Plant Industry have sponsored a long list of terms compounded in exactly the way for which this critic insists that "no warrant exists." These and others are applied to new kinds (not varieties) of citrus fruits, namely, citrange, citrandarin, citrangarin, citrangedin, citranguma, citrangquat, clemelo, limelo, limequat, orangelo, oranguma, orangequat, satsumelo, siamelo, siamor, and tangelo. All these words were created by "dismembering" such words as citron, kumquat, lime, mandarin, orange, pomelo, satsuma, tangerine, and others, and "using certain of their letters." (Cf. recent volumes of the JOURNAL OF AGRICULTURAL RESEARCH, and especially their collected use in Jour. Agr. Res., 28:227-239, 1924.)

7. The reason for discussion of chemical, genetic, and mathematical symbols is not clear. The median terms suggested are words, not symbols, and there can be no comparison. As a matter of fact, some of the symbols already are found in the dictionaries as abbreviations, and presumably "pH," "F_1," etc., will be found in the dictionaries when new editions appear.

8. The use of these median terms was suggested exactly with the view of "accomplishing a precision together with a brevity highly desirable in technical publications." Nothing could be less precise than the common use of the term "medium" in such a phrase as "medium plants." On the other hand, the phrase "midheight plants" is instantly clear.

9. The author of the critique disclaims having any objection to the coining of new words The variety of arguments presented, and their obvious weaknesses, however, are symptomatic of what would generally be regarded as an acute case of neophobia.

10. The Commitee was not engaged in defining terms in the paper criticized It properly assumed that the scientist knew the meaning of the terms he was using as lesser and greater extremes. If he did know this, he naturally knew also the meaning of the median term. The sole object of the Committee was to set forth the principles on which such median terms are formed and furnish suggestive illustrations of those principles.

11 Without discussing whether the proposed new vocabulary will "add materially to the clarity of scientific papers," it may be admitted that the critic probably is right in his statement that users of it seem "likely to furnish food for the cartoonist and the vaudeville humorist." That likewise was the happy fate of publications of the U. S. Department of Agriculture on the "Ox Warble" and the "Bedbug."

12. Special disapproval is given by the writer of the critique to the word "stouth," suggested as an equivalent of stoutness. The term "stouth" is merely one of an attractive alternative series of terms, including breadth (broadness), fulth (fullness), goodth (goodness), length (longness), strength (strongness), width (wideness), and others. As the Committee pointed out (page 184), "stouth" is not a new word but an old term having exactly the meaning of stoutness. Thus the Committee did give "a definition, an explanation." When "stouth" is presented as the median term in "the Committee's tabulation 'slender-midstouth-stout' " there can be no doubt whatever as to its meaning.

13. It is true, as the critique points out, that, according to the dictionaries, "stouth" means also "a store or hoard" and "stealth or theft." The dictionaries point out further, however, that these meanings largely are restricted to Scotland and at present mostly obsolete. The writer of the critique might have pointed out also that "stout" itself means not only strong or fleshy, but likewise (a) arrogant and stubborn, (b) strong ale or beer, (c) a gnat, gadfly, or moth, and, finally, (d) a shock of grain bundles (local, U. S.). However, when we speak of a stout man or a stout heart we know exactly what we mean.

14. The term "stouth" was not proposed as "an act of desperation forced by the obvious impractibility of defending the use of 'mid-stoutness' as a median adjective." As a matter of fact, what is there more amusing about the clearly understood phrase, "the midstoutness hogs," than about the wholly nonexplanatory phrase, "the medium hogs?" The former tells its story instantly. The latter sends the reader scurrying in quest of other sentences telling what "medium" condition is to be understood. The phrase "the midstoutness hogs" is the shortest, clearest form of "the hogs of midstoutness," which in turn is shorter than "the hogs having a medium degree of stoutness."

15. As stated in its report, the Committee welcomes constructive criticism, based on adequate consideration of the subject. The fact that the critique under discussion descends finally to ridicule is perhaps the best evidence that the paper criticized is fundamentally sound. Vociferous argument, open ridicule, and even legislative prohibition, greeted the bathtub when it was first introduced. It is seen to be in fairly common use today. If the proposals of the Committee commend themselves to thinkers and writers they will survive, no matter what is said against them. If not, they will perish, no matter what is said for them.

NOTE

LONGEVITY AND VIABILITY OF KAFIR SEED

In breeding work with crops it is frequently desirable to resort to remnant seed, which may often be several years old, for the purpose of comparison with newly developed strains. Likewise, in genetic studies paternal material is usually preserved and often utilized in answering questions that may arise as the investigations proceed along major lines, or such remnant seed may furnish material for the study of minor phases of inheritance incidental to the main problem. In such instances, and also when used for general planting seed, it is of interest and importance to know how long stored seed of the major field crops may be expected to retain their viability under ordinary conditions of storage.

In inbreeding work with Standard Blackhul kafir at the Texas Experiment Station during the past 10 years it was found desirable to preserve remnant seed of different strains from year to year. Incidental to tracing back the origin of certain chlorophyll deficiencies in these inbred lines, the writer had occasion to use some of this old seed which had been grown in 1917. Since that time the seed had been stored in seed envelopes in the laboratory at Lubbock, which is located in a region of comparatively low humidity and rainfall.

In 1924, when first tested for germination, this seed, then seven years old, proved to have a viability of 88%. Tested again in 1926 and 1927 it germinated 79.5 and 65%, respectively. The latter figure includes 2% of seeds which germinated but produced very weak sprouts.

Assuming an original viability of approximately 100% for the seed in 1917, the first seven years in storage resulted in a loss of only 12% in germinability, while the last three years of the 10-year period reduced the viability 23%. These results indicate that kafir seed, and probably that of other similar grain sorghums, stored under laboratory conditions, have a rather consistent germinating capacity up to seven years, after which they lose their viability quite rapidly, and judging by the rate of decline, are of little value after 10 years. —R. E. Karper, *Department of Agronomy, Texas Agricultural Experiment Station, College Station, Texas.*

BOOK REVIEWS

THE SELECTION, BREEDING, AND CULTURE OF SUGAR BEET SEEDS IN THE SOVIET UNION

By "The Sakharotrest" (The United Sugar Industry of the Soviet Union). Distributed by the Amtorg Trading Corporation, 165 Broadway, New York City.

Ever since the outstanding Russian work on soil classification, made public a few years back through Professor Glinka's book, scientific men in America have had their eyes on Russia. The pamphlet here called to the attention of American agrononomists rather than reviewed, does not purport to compare in either scope or importance with Glinka's work, but it does present a new angle worthy of consideration by all interested in sugar beets or in sugar-beet breeding.

Certain difficulties in translation have considerably obscured what seems to have been a good plant-breeding exposition in the original Russian. The vigorous (and we might almost say, courageous) attack on sugar-beet improvement by inbreeding attracts the reader's interest. Isolation cages for entire plants and also for single branches seem to have been used consistently, and according to the Russian data, with excellent results, both as to uniformity and as to sugar yield.

The description of the really thorough testing of strains subsequent to their production by inbreeding impresses the careful reader that here is the way sugar-beet breeding *ought* to be done.

About forty half-tones and a half-dozen charts add to the attractiveness of the pamphlet. Lack of legends that really describe, and the obvious mistranslation of a few, somewhat weaken the publication. (G S.)

THE SOILS OF CUBA

By H. H. Bennett and Robt. V. Allison. Washington: Tropical Plant Research Foundation, 1350 B Street, S W. XXIV + 368 pp. map, illus. 19 8.

This book and accompanying map give the results of the first attempt at the differentiation of the soils of any tropical country to any extent other than a broad general description without a map. The differentiation is based on the same criteria as those used in the U. S. Soil Survey.

After an introduction in which the most probable relations between soil characteristics and the problems of sugar production in Cuba are discussed, the predominant characteristics of Cuban soils are described followed by a description in considerable detail of the various important groups of related soils and the soil series of which each group is composed. This chapter includes 65 of the 400 pages in the book. Chapters IV to VII inclusive constitute the most important part of the book and cover 200 pages. These chapters deal with the details of soil character and distribution by geographic

areas, each area being defined as one in which a given soil or a few closely related soils are dominant. Not only is this a description of Cuba from the point of view of soil geography but it covers a description of the actual agriculture, an interpretation of the existing status of agriculture as a local product of soil characteristics, and a discussion of the agricultural possibilities of each region on the basis of the fundamental character of its soils. This series of chapters is the most important part of the book, including not merely discussion of soil characteristics but descriptions of the island of Cuba as a soil and agricultural region. Short chapters on The Relation of Soils to Agriculture in Cuba, Salt in Cuban Soils, Soil Classification, glossary, index, and tables follow. The book is illustrated by a large number of well selected and well reproduced halftones and a large number of complete chemical and mechanical analyses of Cuban soils. This alone constitutes a scientific contribution of the greatest importance. When it is borne in mind that there are on record not more than 50 chemical analyses of any kind of tropical soils in all tropical countries outside Cuba the importance of this contribution will be realized. It is much more important, however, than this bare comparative statement indicates. These analyses show the composition of *soil profiles* to many feet in depth, constituting practically all of the *complete* analyses of *complete soil profiles* of tropical soils now in existence.

The chemical results include a number of analyses of those iron concretions which constitute so striking a characteristic not only of Cuban soils but of all tropical soils, and show the relative composition of these bodies and of the fine material of the soils in which they are found.

Cuba lies south of the Tropic of Cancer and geographically therefore within the tropics. The characteristics of considerable areas of its soils show that it lies well within what may be called the pedological tropics. Its soils are tropical soils, their features making it unnecessary to invoke the aid of the climate, the latitude, or even the character of the vegetation in order to show that they were developed in the tropics. This applies manifestly, not only here but elsewhere in the world to the fully developed, or as we say in the United States, the mature soils. In every region there are immaturely developed soils, some very immature, and others representing various degrees of approach toward maturity. An examination of the chemical composition of the Nipe, the Pinar del Rio, Greenville, Herradura, Estrella, and Mocarrero soils shows the presence of those characteristics now known to characterize maturely developed tropical soils. These are the low percentages of the alkalies and alkaline earths, the high percentage of iron or of alumina, or of both, and a low percentage of silica except in those cases where free quartz is present, such as in sandy loams.

The strongly marked tropical character of these soils is shown not merely in their chemical composition. The field man is not dependent wholly on such results. They are valuable to him in giving him definite figures for what otherwise would have to be expressed in less

definite language, but the physical and profile characteristics of these soils are equally striking and enable the student of soils in the field to identify them without difficulty. The color, structure, surface compaction, and the concentration of iron shown by intensity of color are striking and unmistakable field characteristics. The barrenness of the natural vegetation on these soils is another striking feature.

Such soils cover but a small part, however, of the total area of Cuba. They occupy a small area on the high plateau of extreme eastern Cuba and the sandy western end of the island, and while the latter are true tropical soils they are not unproductive when properly managed.

The great central part of the island extending from some 50 miles west of Havana to the longitude of Santiago de Cuba is covered by a wide variety of soils, large areas of which are highly productive. The soils of this region may be grouped into four general groups. These are,

1. The large areas of strikingly red soils, heavy in texture but generally well granulated and generally productive of good yields of sugar cane and other crops.

2. The brown young soils of the eastern part of the island seemingly derived from young geological deposits. They have not yet been thoroughly leached, even in some places containing salts.

3. Shallow soils. Of these there are two general kinds. One of these includes soils developed, such development as has taken place, from old, usually highly altered crystalline rocks. The other is derived from limestones and marls. The former of these two groups constitute lands valuable mainly for pasture. The latter are relatively productive for a wide range of crops, including sugar cane.

4. The fourth group includes sandy soils, seemingly having developed from remnants of a sandy cover which may have been spread over a large part of the island originally. The largest area occurs on the highest part of the upland of the central part of the island, not including the low mountains, in a locality which has been protected from erosion by occupying an area which the drainage has not yet attacked with vigor. This includes the Sabana de Santo Domingo.

5. A fifth group of soils include the marshes and wet lands and keys along the coast.

This book is a notable contribution and deserves to be read by all persons who are interested in the soils of the world or the soils and agriculture of the tropics.—C. F. MARBUT.

AGRONOMIC AFFAIRS

HARD SPRING WHEAT BREEDING CONFERENCE

The first annual Hard Spring Wheat Breeding Conference was held at the North Dakota Agricultural College at Fargo, North Dakota, on March 27, 1928. The conference was called to promote unified action in the development of a wheat breeding program suited to the needs of North Dakota, South Dakota, Minnesota, and Montana. The conference was attended by agronomists, plant pathologists, plant breeders, and cereal chemists from these four states and from the prairie provinces of Canada. In addition to the representatives of the state eductional institutions, there were present representatives from the elevator and milling interests, from the railroads, and the state governments, as well as a number of seedsmen, seed growers, and farmers. The conference was attended by over 60.

Resolutions were adopted endorsing a proposed program to enlarge the activities of the United States Department of Agriculture looking toward more fundamental research in the physiology, pathology, cytology, and genetici of wheat and its pathogens, and in the ecological and meteorological conditions which surround the wheat plant and its attacking pathogen. Greater support for more fundamental research in the field of cereal chemistry and technology was urged. Resolutions were adopted asking for increased facilities for the routine field and laboratory testing of the material being produced by the plant breeder. It was the sense of the conference that a greatly enlarged program of wheat improvement for the Northwest should be undertaken by both the United States Departmen t o Agriculture and the several state experiment stations.

The following program was presented:

President J. L. Coulter, North Dakota State College, Presiding.
Address of welcome, J. L. Coulter.
Seeing all sides of a complex question, C. R. Ball.
The rôle of plant breeding in crop improvement, H. K. Hayes.
Wheat improvement, and what may be expected from breeding for disease-resistance, yield, and quality, J. A. Clark.
The interdependence of the geneticist and pathologist in wheat breeding, and their way of working together, E. C. Stakman and Olaf S. Aamodt.
Relation of the cereal chemist to wheat breeding, C. E. Mangels.
A first approach in securing commercial rust-resistant wheats, L. R. Waldron.

Possibilities and difficulties in the field of radical wheat crossing, E. S. McFadden.
Demonstration, distribution, and conservation of new wheat varieties (to be considered in committee), E. G. Booth.
Maintaining purity of the varieties (to be considered in committee), H. L. Bolley.
New wheat varieties from the point of view of the commercial miller, M. A. Gray and T. C. Roberts.
The program: Improved wheat, Committee Report.
The program: Organization and cooperation, Committee Report.
The program: How to finance it, Committee Report.
The Canadian wheat improvement program in action, C. H. Goulden.

Officers were elected as follows:

President, J. L. Coulter, North Dakota; *Vice-President*, Andrew Boss, Minnesota; and *Secretary*, L R. Waldron, North Dakota.

NEWS ITEMS

The Journal of the Ministry of Agriculture for Northern Ireland, the initial number of which has just appeared, is intended as a medium of publication for the several research divisions attached to the Ministry and is to be issued annually. The first number contains several articles on agronomic subjects.

H. H. York, Forest Pathologist of the New York State Conservation Commission, spent several weeks at the College of Agriculture at Ithaca recently in a study of the soils work underway there.

F. L. Higgins has been appointed agronomist in charge of the experiment station at Fairbanks, Alaska, to succeed G. W. Gasser who resigned January 1 to accept a professorship in the Alaska Agricultural College.

J. Arthur Harris, Head of the Botany Department, University of Minnesota, addressed the North Dakota Academy of Science at its annual meeting at Fargo on May 4 on the subject, "The Biological Value of Practical Agricultural Experimentation."

H. A. Lunt of the Department of Agronomy, Illinois Agricultural Experiment Station, has been appointed to the position of Assistant in Forest Soils Research, Department of Soils, Connecticut Agricultural Experiment Station, to begin his duties on the completion of his graduate study at the University of Illinois, about August first.

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VOLUME WEIGHT OF CERTAIN FIELD SOILS[1]

M. B. HARLAND AND R. S. SMITH[2]

The studies reported in this paper on the volume weights of certain Illinois soils were undertaken primarily for two purposes, *viz.*, first, to secure values upon which the computation of acre-weights could be based; and second, to determine if certain extensive soil types in Illinois have characteristic volume weights.

LITERATURE

The various methods which have been employed in attempting to measure volume weight may be separated into two groups. One of these includes only laboratory methods on disturbed soils, while the other includes field and laboratory determinations upon structurally unchanged soils. Laboratory determinations on prepared soils are of very doubtful value, since structural alterations cannot be avoided. The various methods published which do not include artificial preparation of the sample are briefly outlined below.

King (5)[3] proposed the use of a tube of known volume which was driven into the soil, and the removed soil weighed. Warington (9) cites results from a similar procedure used at Rothamsted prior to 1900. He recommends that the tube be not less than 6 inches in diameter and states that successively deeper samples can be secured by digging each sample out with a spade. Stevenson (7) constructed a rather elaborate sampler with a battery of cutting teeth which removes a vertical cylindrical section. This section is then removed from the sampler with as little structural disturbance as possible.

[1]Contribution from the Division of Soil Physics, Department of Agronomy, University of Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication March 8, 1928.

[2]Associate and Chief, respectively, in Soil Physics. The authors wish to thank R. S. Stauffer for his assistance in a part of the field work.

[3]Reference by number is to "Literature Cited," p. 541.

Brown, MacIntire, and Cree (1) reported a new method in which a cube of surface soil was carefully removed and its volume determined by displacement of water after applying an enveloping coat of paraffin. Trnka (8) is said to consider this method the most accurate and therefore of the greatest research value. Shaw (6) has published results secured by the same procedure, which he states was worked out by Brown and associates under his direction. Shaw secured samples from beneath the surface soil by digging a hole of sufficient cross-section and depth to allow the operator to secure the successive samples from the side-wall. Frosterus and Frauenfelder (3) report results secured from volumetric readings obtained from displacement of mercury by the soil sample. Frear and Erb (2) adopted a radically different method of attack by determining the volume of the hole resulting from the removal of the sample, measured volumes of sand being used for this purpose. Israelson (4) measured the volume of the hole from which the sample had been taken by inserting a thin-walled rubber tube and filling it with measured quantities of water. He used an auger to remove the desired sample and could remove successively deeper samples from the same hole and determine their volume by using longer tubes.

None of these methods is entirely satisfactory for all soils King's tube tends to compact clayey samples, and penetrates gravelly or stony soils with difficulty, if at all. The latter objection applies also to Stevenson's sampler. The mercury displacement method may be used only with cohesive soils. The use of either the Shaw or the Frear and Erb procedure in very sandy soils is difficult, though the latter is probably the best method yet proposed for incoherent soils. The auger used by Israelson may cause some compaction in clays, and is not satisfactory in gravelly soils. The Israelson method is probably the best for routine determinations, and the Shaw method for studies in most soils where exact horizon separations are desired. The Israelson method requires a minimum amount of labor and is relatively rapid. The results secured with it check closely with those secured with the Shaw method. The Shaw method, however, offers better opportunity for detection of rodent burrows or other objectionable features, allows of more accurate horizon separations, and is more applicable to gravelly soils.

PROCEDURE

The Israelson method was used in securing the results reported in this paper. An effort was made to run determinations only upon virgin soils, or upon soils which had been undisturbed for a considerable period. Locations were usually chosen on sodded strips along

highway fences, on borders of experiment fields, or in country schoolyards. Ten determinations were made on each soil type, within an area of a few square rods. A sharp shovel and knife were used to prepare the proposed location of each hole. This preparation consisted of careful removal of the matted grass and grass roots at the immediate surface, and gently scraping the bared soil to as nearly a level plane as possible. This plane thus became the upper limit of subsequent additions of water in measuring the volume of the hole. A steel rod was set with its pointed end centering the proposed hole and marking the surface level. This rod was fastened by apparatus clamps to a filed mark on an ordinary soil auger which was set near the proposed hole. The rod could thus be swung out of the way while boring and later reset with its point locating the former surface level.

It was found advisable to start each hole by removing a small inverted cone of soil with a sharp knife. The auger could then be started in the desired spot with a minimum disturbance of the adjacent surface. An Iwan pattern auger was used. This type of auger has a halved cylindrical barrel with two side and four bottom cutting edges. The bottom cutting edges are flared to cut a hole a trifle more than 2¼ inches in diameter. The barrel of the auger is slightly smaller than this, thus tending to minimize the compaction of the side walls of the hole.

In the work reported in this paper, each horizon was removed as a unit and its volume weight determined. Proposed locations were examined with a soil auger to secure the approximate depth of each horizon. The horizon separations were thus known approximately before starting to take the volume weight samples. Any zone deemed transitional in character was removed as a part of the horizon just above it. As each horizon sample was removed with the auger, it was placed on an oilcloth and then transferred to a canvas bag. A rubber tube of suitable length was placed in the hole and filled with water to the level of the steel pointer which had been reset. The rubber tubes ranged in length from about 8 to 44 inches; and in diameter they were approximately the same as the auger barrel, and so were slightly smaller than the holes bored. The volume of tube wall and bottom was determined by displacement of water, and a suitable correction added to each water reading. One-litre, 0.5-litre, and 0.25-litre volumetric flasks and a 0.1-litre graduated cylinder were used to measure the water required to fill the tube. The total error due to measurement of water was thus reduced to less than 5 cc.

The water in the tube was then pumped out, the tube removed and dried, and the succeeding horizons removed and their volumes measured. Each sample was taken to the laboratory and placed in an oven to dry. The oven doors were left open for at least three days to expedite drying and were then closed and a temperature of 105° C maintained for three days. Each sample was then weighed as soon as cooled after removal from the oven.

RESULTS

The results of 14 sets of volume weight determinations upon 13 soil types are reported in this paper. These types are reported in part under the names given them by the Illinois Soil Survey, since correlation with the Bureau of Soils nomenclature is not complete. Brief descriptions of profile sections of each type are also included. The horizons are designated in the conventional manner and the mean thickness of each is given to the nearest half-inch. It will be noted that the total thickness of each type section is exactly 40 inches. Although many individual holes were an inch or more deeper, and a few were shallower, all of them were corrected to the arbitrary 40-inch depth by numerical reduction or expansion of the deepest horizon. The total weight of each 40-inch type section was calculated by addition of component horizons. The thickness and volume weight of each horizon and the volume weight of each 40-inch section reported in Table 1 is the mean of 10 individual determinations. The probable errors shown were calculated by Peter's formula: $P.E. = \pm 0.8453 \frac{\Sigma (v)}{n\sqrt{n-1}}$.

The following short type descriptions are taken from the field notes.

CARRINGTON SILT LOAM—CHAMPAIGN COUNTY, ILLINOIS

A_1— 8½ inches—Brown, friable, silt loam, occasional pebbles.
A_2—11 inches—Yellowish brown, friable but slightly compact, silt loam, occasional pebbles.
B_1— 9½ inches—Yellow, compact, slightly mottled, silty clay loam, sandy, gravelly drift at 25 to 30 inches.
C_1—11 inches—Mottled, friable, sandy and gravelly silty clay loam.

TAMA SILT LOAM—BUREAU COUNTY, ILLINOIS

A_1— 8 inches—Brown, friable, silt loam, slight yellowish tint.
A_2—10 inches—Yellowish brown, friable, slightly compact silt loam.
B_1— 9½ inches—Yellow, very slightly compact and plastic, clayey silt loam.
C_1—12½ inches—Yellow, friable, silt loam.

TABLE 1.—*Volume weights of horizons and of composite 40-inch sections of certain soil types, average of 10 determinations.*

Soil type	Horizon A_1	A_2	B_1	C_1	40-inch section
Carrington silt loam	1.287±.007	1.294±.008	1.355±.008	1.575±.010	1.381±.006
Tama silt loam	1.277±.014	1.260±.009	1.316±.009	1.499±.011	1.347±.005
Muscatine silt loam (Henry county)	1.204±.011	1.268±.006	1.321±.004	1.401±.003	1.302±.004
Muscatine silt loam (Champaign county)	1.276±.008	1.283±.012	1.358±.008	1.349±.006	1.319±.006
Grundy silt loam	1.240±.008	1.274±.015	1.307±.009	1.474±.006	1.341±.005
"Loessial Clyde" clay loam	1.283±.019	1.268±.014	1.350±.012	1.429±.011	1.331±.008
Brown Sandy Loam[a]	1.491±.011	1.449±.011	1.451±.011	1.536±.008	1.475±.006
Clinton silt loam	1.456±.011	1.479±.006	1.456±.011	1.483±.003	1.470±.005
Edina silt loam	1.221±.014	1.387±.008	1.316±.012	1.541±.015	1.367±.007
Gray Silt Loam On Tight Clay[a]	1.509±.008	1.561±.007	1.509±.011	1.557±.009	1.536±.006
Gray Silt Loam On Orange-Mottled Tight Clay[a]	1.328±.007	1.251±.009	1.294±.004	1.590±.007	1.376±.004
		1.275±.008[b]	1.478±.011[c]		
Yellow-Gray Silt Loam On Tight Clay[a]	1.460±.008	1.492±.013	1.451±.008	1.643±.018	1.511±.005
Yellow-Gray Silt Loam On Compact, Medium-Plastic Clay[a]	1.619±.014	1.527±.010	1.493±.005	1.757±.004	1.599±.005
Yellowish Gray Silt Loam On Orange-Mottled Tight Clay[a]	1.352±.009	1.276±.013	1.299±.007	1.695±.005	1.439±.004

[a]Names and capitalization follow Illinois Soil Survey.
[b]A_3 horizon. [c]B_2 horizon.

MUSCATINE SILT LOAM—HENRY AND CHAMPAIGN COUNTIES, ILLINOIS

A_1— 9½ inches—Brown, friable, silt loam.
A_2—9–9½ inches—Light brown, friable silt loam.
B_1—9–10½ inches—Mottled, moderately compact and plastic, silty clay loam.
C_1—11–12 inches—Mottled, friable, silt loam.

GRUNDY SILT LOAM—MCLEAN COUNTY, ILLINOIS

A_1— 9½ inches—Dark brown, friable, silt loam.
A_2— 6 inches—Brown, friable, silt loam.
B_1— 9½ inches—Mottled, compact, plastic clay.
C_1— 15 inches—Mottled, friable, silt loam.

"LOESSIAL CLYDE" CLAY LOAM—CHAMPAIGN COUNTY, ILLINOIS

A_1— 8 inches—Black, friable, silty clay loam.
A_2—12 inches—Drab, moderately plastic, clay loam.
B_1—11 inches—Drabbish gray with dull yellow splotches, compact, plastic clay.
C_1— 9 inches—Mottled, fairly friable, silty clay loam.

BROWN SANDY LOAM—IROQUOIS COUNTY, ILLINOIS

A_1— 9 inches—Brown, friable, sandy loam.
A_2—10 inches—Yellowish brown, friable, sandy loam.
B_1—11 inches—Mottled, rather plastic and compact, sandy clay loam.
C_1—10 inches—Golden yellow sand.

CLINTON SILT LOAM—CHAMPAIGN COUNTY, ILLINOIS

A_1— 8 inches—Yellowish gray, slightly compact, silt loam.
A_2— 9 inches—Grayish yellow, friable, silt loam.
B_1—11 inches—Mottled, compact, plastic, clay loam.
C_1—12 inches—Mottled, friable, clayey silt loam.

EDINA SILT LOAM—HANCOCK COUNTY, ILLINOIS

A_1— 8 inches—Grayish brown, very friable, silt loam.
A_2—11 inches—Gray, fairly friable, silt loam.
B_1—11½ inches—Heavily mottled, compact and plastic clay.
C_1— 9½ inches—Mottled, compact, rather plastic, silty clay loam.

GRAY SILT LOAM ON TIGHT CLAY—CUMBERLAND COUNTY, ILLINOIS

A_1— 7 inches—Gray, fairly friable, silt loam, slight yellowish cast.
A_2— 8½ inches—Light gray, friable, "ashy" silt loam.
B_1—12 inches—Heavily mottled, compact, plastic clay (tight).
C_1—12½ inches—Mottled, friable, clayey silt loam.

GRAY SILT LOAM ON ORANGE-MOTTLED TIGHT CLAY—WAYNE COUNTY, ILLINOIS

A_1— 8 inches—Grayish brown, friable, silt loam.
A_2— 7 inches—Grayish yellow, friable, silt loam.
A_3— 3 inches—Yellow, compact, silt loam, orange splotching.
B_1— 8 inches—Gray, compact, moderately plastic clay, heavily splotched with orange.

B_2— 6 inches—Mottled, compact, plastic clay, with brick red to yellowish brown splotches.
C_1— 8 inches—Mottled, friable, clayey silt loam.

YELLOW-GRAY SILT LOAM ON TIGHT CLAY—WAYNE COUNTY, ILLINOIS

A_1— 6 inches—Yellowish gray, friable, silt loam.
A_2—13 inches—Yellowish gray, friable, silt loam.
B_1—11 inches—Yellowish gray, plastic, somewhat compact clay.
C_1—10 inches—Yellowish gray, moderately plastic, clay loam.

YELLOW-GRAY SILT LOAM ON COMPACT, MEDIUM-PLASTIC CLAY—WAYNE COUNTY, ILLINOIS

A_1— 6½ inches—Yellowish gray, friable, silt loam.
A_2—10½ inches—Grayish yellow, friable, silt loam.
B_1— 10 inches—Mottled, grayish yellow, somewhat plastic clay.
C_1— 13 inches—Mottled, friable, silty clay loam.

YELLOWISH GRAY SILT LOAM ON ORANGE-MOTTLED TIGHT CLAY—WAYNE COUNTY, ILLINOIS

A_1— 10 inches—Brownish gray, friable, silt loam.
A_2— 5 inches—Yellowish gray, friable, silt loam.
B_1—11 inches—Mottled, somewhat plastic clay.
C_1—14 inches—Yellow, very friable, fine sandy silt loam.

DISCUSSION

The tabulated results show both marked variations and similarities in volume weight. The Carrington, Tama, Muscatine, Grundy, and "Loessial Clyde" profiles correspond closely in weight in spite of differences in texture and organic content. The Carrington section is somewhat heavier because of the drift in the C horizon. There is not, however, uniform correlation between texture and volume weight in the C horizons of the various types. Brown Sandy Loam has a significantly higher weight than the silty soils, probably because of its greater percentage of coarser particles. A relatively high volume weight apparently is associated also with a low organic content, since the Clinton silt loam results are closely comparable with those on Brown Sandy Loam. The Edina profile shows one result of particular interest. The A_2 horizon of this type approaches an "ashy" condition and has a higher weight than the other silty A_2 horizons of the dark-colored soils. The C horizon of Edina silt loam, of Brown Sandy Loam, and of Carrington silt loam agree closely in weight in spite of decided textural differences.

The other five soil types reported are considered more mature than those previously discussed. They seem as a group to be heavier, probably because of both low organic content and high compaction. There is a noticeable tendency for the relatively impervious B hori-

zons of these light-colored soils to have a higher volume weight than the more pervious subsoils of the dark-colored soils. The "ashy" A_2 horizon of Gray Silt Loam On Tight Clay is relatively heavy, as in the Edina silt loam.

The differences in weight of the 40-inch sections of the various types may be more clearly presented if given in terms of pounds per acre. The common assumption is that mineral soils weigh about 12 million pounds per acre to a depth of 40 inches. This corresponds to a volume weight of about 1.33. We find that the weight of the dark-colored silty soils is near the commonly assumed weight. The Carrington silt loam alone is decidedly heavier. Brown Sandy Loam and Clinton silt loam, however, exceed the conventional weight by more than 1,300,000 pounds. The older light-colored soils are also heavy, ranging from an excess of 0.5 million to 2.5 million pounds over 12 million.

SUMMARY

A maximum variation in weight of about 2.75 million pounds in 40 acre-inches is shown in the soil types studied. Both the upper and lower extremes are silty soils. Very sandy, light-colored soils might increase the range, and peaty soils undoubtedly would do so.

In dark-colored silty soils, the A, B, and C horizons show progressively greater weight with increase in depth through 40 inches examined.

Sandy soils and light-colored soils in the same region as the dark-colored ones show a decidedly greater weight as a result of their coarser texture and decreased organic content. There seems to be no marked difference in volume weight between silty and clayey soil sections.

Mature soils seem to be heavier than younger soils. This greater weight probably is due in part to lower organic content, and to the presence of "ashy" horizons which have a high volume weight. The B horizons, especially if relatively impervious, and the C horizons, for no reason which is apparent, show the same trend. There is more variation in weight between types in the older light-colored soils than in the younger dark-colored ones. Deeper horizons tend to be heavier than shallower ones, whether fine or coarse textured, in both the light and dark-colored soils.

Clayey horizons are seemingly no lighter in weight than silty horizons, and possibly are heavier. Sandy horizons are probably heavier than finer-textured ones, though the data are not conclusive on this point.

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SEASONAL BEHAVIOR OF ALFALFA FLOWERS AS RELATED TO SEED PRODUCTION[1]

JOHN W. CARLSON[2]

INTRODUCTION

A few researches have concerned themselves with the structure and pollination of alfalfa flowers. Others have been made to compare the relative value of artificial tripping of the flowers in seed production. In none of these studies has an attempt been made to observe carefully the seasonal behavior of the individual flowers. No effort has been made to study the changes involved and the duration of the stages as they are related to the subsequent seed crop.

In view of the importance of this study to alfalfa seed growers, an investigation was begun on the Uintah Basin Alfalfa Seed Experimental Farm in 1926. The chief purpose of the work has been to observe carefully the behavior of alfalfa flowers growing under natural conditions while in the process of forming seed. An attempt has also been made to interpret this behavior in terms of effects upon the resulting seed crop.

REVIEW OF LITERATURE

Brand and Westgate[3] consider insects to be essential agents in bringing about the tripping and proper pollination of alfalfa flowers. Bumblebees (*Bombus* spp.) and wild bees (*Megachile* spp.) are generally considered to be the most efficient. At the Arlington (Virginia) experimental farm they found that plants artificially tripped by exerting pressure successively over the whole plant yielded 25.5% more pods than did plants in adjoining rows not so treated. At Chico, California, they found an increase of 129% in the number of pods.

Piper, *et al*[4] present a review of the work of early European investigators on problems dealing with the pollination of alfalfa flowers.

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The writer wishes to express appreciation for the helpful suggestions offered by Dr. George Stewart under whose direction these experiments were made.

[3]BRAND, CHARLES J., and WESTGATE, J. M. Alfalfa in cultivated rows for seed production in semi-arid region. U. S. D. A. Bur. Plant Ind. Cir. 24. 1919.

[4]PIPER, C. V., *et al.* Alfalfa seed production: Pollination studies. U. S. D. A. Bul. 75. 1914.

The work of Henslow, who is credited with having first studied the alfalfa flower with a view to locating the explosive force manifested in tripping, is given special attention. These early investigators did not study pollination as related to the subsequent seed crop. They disagree in their conclusions as to the importance of insects in tripping the flowers.

Piper's studies deal largely with tripping and pollination in relation to the development of seed. It was found that 30.68% of the flowers set pods when artificially tripped as compared with 16.76 % when allowed to develop naturally. Pods were noted to form from flowers not tripped but only in about 5% of the cases. Some of these data are open to question, as the flowers used were enclosed in netting, which condition is unnatural. A few cases of automatic tripping were seen to occur. The number of seeds per pod in artificially tripped flowers is usually less than in naturally fertilized flowers, the ratio being 1:1.72 in the case of flowers artificially tripped and 1:2.22 in the case of flowers allowed to develop naturally.

Under conditions of natural development few-flowered racemes were found to produce proportionally more pods than many-flowered ones. Cross-pollination is more potent than self-pollination, while pollination from another flower on the same plant gives practically the same result as self-pollination.

Studies by Hay[5] indicated that neither lack of tripping, time of tripping, nor color of flower influenced seed setting in alfalfa sufficiently to account for the poor yields. After tripping 960 flowers by means of a tooth pick and using an equal number of untripped flowers as checks, he found that 9.48% of the tripped flowers and 5.94% of the untripped flowers formed seed pods. While the percentage of pods formed in both cases is very low, the ratio in favor of artificial tripping is very similar to that obtained by Piper, *et al* and also to that obtained by the writer as shown in Table 1.

EXPERIMENTAL WORK

When the commercial seed grower examines his crop and thinks of it in terms of probable yield, he notes first the apparent number of racemes containing mature pods. He observes also the relative number of pods on the individual racemes. It is obvious that both a large number of racemes bearing pods and a reasonably large number of pods on each raceme are essential to a good crop of seed. In order to study the first of these conditions the experiment here reported was conducted.

[5]Hay, W. D. Does artificial tripping of alfalfa blossoms increase seed production? Sci. Agr., 5: 289, 290. 1925.

PERCENTAGE OF RACEMES THAT BEAR PODS WITH MATURE SEED

In 1926, eleven representative locations were chosen in six fields of the Uintah Basin seed area. At each of these locations a stake was set and in its vicinity 100 racemes of alfalfa flowers were marked with small jewelry tags. Most of the flowers were in full bloom at the time of labeling. They were not visited again until the fields in which they were located were ready to be harvested. A re-count was then made of the racemes and the number on which pods had formed was determined. No distinction was made between racemes bearing many and those bearing only a few pods. In 1927 the procedure was the same, except that the number of representative locations was greatly increased and all of them were located on the plats of the experimental farm. The number of racemes marked at each location was also smaller, but the total number observed during the season was somewhat greater than for 1926. Two series were studied, one during June and the other in July. The data for each study are reported in separate columns in Table 1.

TABLE 1.—*Percentage of racemes that bore pods containing mature seed.*

	July 1926		June 1927		July 1927		Total	Weighted
	Number	%	Number	%	Number	%	number	average %
Number of locations at which racemes were studied........	11	—	44	—	40	--	95	—
Number of racemes labeled giving data........	906	—	556	—	580	—	2,042	--
Racemes producing pods	677	74.7	470	84.3	531	91.5	1,678	82.1
Racemes producing no pods.......	229	25.3	86	15.4	49	8.4	364	17.8

An examination of the data in this table shows that the average percentage of racemes producing pods varied from 74.7 in 1926 to 91.5 in July, 1927. The average for June, 1927, was 84.3%. These data show that there is some fluctuation in the amount of complete stripping from racemes that occurs during various seasons and also at various times during a single season. Of the 2,042 racemes studied during the three periods, 82.1% produced pods. If these numbers can be taken as representative of the fields in which they were located, the data may be assumed to show to what extent this type of stripping may influence the seed yield.

PERCENTAGE OF FLOWERS IN INDIVIDUAL RACEMES THAT FORM PODS WITH MATURE SEED

Observations seemed to show that the percentage of flowers stripping from each individual raceme to be proportionally greater and more important from the standpoint of the seed crop than is the complete stripping of all the flowers from some of the racemes.

Inasmuch as previous investigators had emphasized the importance of tripping before the flowers could set seed freely, it was thought advisable to observe very closely the amount of natural tripping that occurred and to do some artificial tripping for comparison. To test this point and to provide for the dual purpose of the experiment, a special order was followed in labeling the racemes studied. In 1926, ten representative locations were chosen on the plats of the experimental farm. At each location five pairs of racemes were numbered 1 and 2, 3 and 4, and so on to 10. Small tags attached to the base of the racemes were used as markers. Both members of a pair were always located on the same secondary branch of the mother plant, but the different pairs at each location were not always placed on the same plant. In selecting a pair, the object was to get two racemes with flowers as nearly equal in number as possible and nearly in the same stage of development. Since they were located on the same branch they were generally exposed to the same environmental conditions.

The flowers on all the racemes having the odd number of a pair were allowed to develop naturally after all wilted ones had been removed with a pair of scissors and the remainder counted. Daily observations were made of the flowers to determine the number that had become tripped. The standard was clipped from all tripped flowers. This method of branding provided against the flower being counted a second time on subsequent visits. The daily visits were continued until the flowers had formed green pods or had become stripped. In this way accurate data were obtained on the number of the flowers that became tripped under natural conditions of development and on the number that formed pods.

The flowers on the racemes having the even number of a pair were tripped artificially, after all wilted flowers and unopened buds had been removed and a count had been made of the remainder. Tripping was accomplished by inserting a pencil point into the throat of the corolla. All the flowers on the same raceme were tripped in succession. No effort was made to prevent the pollen from one flower being carried to another. Some cross-pollination of flowers is likely to have occurred in the tripping process. Since all wilted and un-

opened flowers had been removed, the remainder could be tripped on the same day. It was not necessary to return to do more tripping upon successive days. However, a daily observation was made of the flowers to insure their being in a tripped condition. In rare cases it was found that the staminal tube had resumed its former position within the keel and the flowers could be tripped a second time. It appeared that this occurred only in very young flowers, which had perhaps been tripped prematurely. Almost without exception, flowers tripped on one day would be found with wilted petals the next day. Artificial tripping seemed to hasten the process of pod formation.

An examination of Table 2 shows some significant differences in behavior of the flowers receiving the two types of treatment. Of the total of 8,217 flowers studied, 4,480 were allowed to develop naturally. The remainder, or 3,737, were tripped artificially. Of those which developed naturally, an average of 10.8% were found to have become tripped. It is not known whether the tripping was automatic or had been caused by insects. The amount of natural tripping varied from 6.2% in 1926 to 12% in June, 1927, the percentage for July, 1927, being 11.5. An average of 37% of the naturally developed flowers formed pods. The percentage varied from 25.6% in 1926 to 41.5% and 36.8% in June and July, 1927, respectively. These data

TABLE 2.—*Percentage of flowers forming pods under natural conditions of development as compared with artificial tripping.*

	July 1926		June 1927		July 1927		Total	Weighted
	Number	%	Number	%	Number	%	number	average %
Total number flowers studied..	1,535	—	3,441	—	3,241	—	8,217	—
Number flowers developed naturally	740	—	1,956	—	1,784	—	4,480	—
Number flowers artificially tripped..	795	—	1,485	—	1,457	—	3,737	—
Number flowers found to have tripped naturally (natural development)..........	46	6.2	236	12.0	206	11.5	488	10.8
Number flowers forming pods when developed naturally............ ..	190	25.6	813	41.5	658	36.8	1,661	37.0
Number flowers forming pods when artificially tripped	450	56.6	1,017	68.4	921	63.2	2,388	63.9

show conclusively that there is considerable range in the amount of variation in pod setting during various seasons. The fluctuations may probably be attributed to changes in weather conditions. Since only a relatively small part of the flowers which developed naturally became tripped, it seems that alfalfa flowers are capable of setting pods rather freely in the absence of tripping.

Of the flowers artificially tripped, an average of 63.9% formed pods. The percentage varied from 56.6 in 1926 to 68.4 in June, 1927. The percentage for July, 1927, was 63.2. Flowers artificially tripped seemed to be influenced by seasonal variations in weather the same as those developed naturally. The ratio of 1:1.7 in pod setting in favor of artificial tripping agrees very well with the results obtained by previous investigators.

PERCENTAGE OF FLOWERS FORMING PODS UNDER CONDITIONS OF NATURAL DEVELOPMENT

To obtain more information as to the percentage of flowers forming pods under conditions of natural development, additional sets of labelled flowers were allowed to make a natural development. The conditions for this experiment were the same as in the previous one, except that the number of racemes and flowers observed was much greater. Table 3 is a summary of the data secured combined with that part of Table 2 that considers flowers under conditions of natural development.

Of a total of 27,050 flowers observed during the seasons of 1926 and 1927, an average of 34.2% formed pods while the remainder stripped. Data from two of the series, one from each season, are furnished which show that about 75% of the pods formed survive until harvest time. The amount of stripping of both flowers and pods was much greater in 1926 than in 1927. While the percentage of flowers forming pods may seem rather low, the condition appears to be a normal one. It appears that on the experimental farm a seed crop of from 300 to 600 pounds of seed to the acre may be obtained, even when only 30 or 40% of the flowers form seed pods.

PERCENTAGE OF GREEN PODS THAT BECOME MATURE AND NUMBER OF SEEDS PER POD (NATURAL DEVELOPMENT VS. ARTIFICIAL TRIPPING)

Table 4 compares natural conditions of development and artificial tripping as to the effects each has upon the pods and seeds after they are formed. Of the pods formed under natural development 77.2% reached maturity without stripping as compared with 71.3% of the artificially tripped. Natural development produced an average of 2.94 seeds per pod as compared with 2.25 seeds for artificial tripping. It is doubtful if the difference in either case is great enough to be significant.

TABLE 3.—*Percentage of flowers forming pods under conditions of natural development.*

	Season of 1926, series No. 1		2		Season of 1927, series No. 1		2		3		4		Total number	Weighted average %
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%		
Total number flowers studied	740	—	1,502	—	9,120	—	1,957	—	1,956	—	1,784	—	27,059	—
Number flowers forming pods	190	25.6	313	20.7	2,862	31.3	4,422	36.9	813	41.5	658	36.8	9,258	34.2
Number flowers stripped	550	74.3	1,189	79.3	6,258	68.7	7,535	63.0	1,143	58.5	1,126	63.2	17,801	65.8
Number pods formed not stripping	78	41.0	a	a	a	a	3,426	77.4	a	a	a	a	3,504	75.9
Number pods stripped	112	58.9	a	a	a	a	996	22.4	a	a	a	a	1,108	24.0

[a]Data not taken.

TABLE 4.—*Percentage of pods formed that became mature without stripping and the number of mature seeds per pod (natural development vs. artificial tripping).*

	Natural development 1926		1927		Artificial tripping 1926		1927		Total number and weighted average Natural development		Artificial tripping	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Total number pods	190		589		450		773		779		1,223	
Number pods reaching maturity not stripping	78	41.0	524	88.9	168	37.3	704	91.0	602	77.2	872	71.3
Number pods lost by stripping	112	58.9	65	11.0	282	62.6	69	8 9	177	22.7	351	28.7
Total number seeds from mature pods	a	a	1,544		a		1,734					
Average number seeds per pod	a		2.94		a		2.25					

[a]Data not taken.

EFFECT OF NUMBER OF FLOWERS PER RACEME ON THE PERCENTAGE OF PODS FORMED

The data secured from the study of flowers in the previous experiments have been classified to show what influence the number of flowers per raceme had on the percentage of pods formed. Of the total of 9,131 flowers on 547 racemes, those on 293 racemes were developed under natural conditions and those on 254 racemes were artificially tripped.

The data (Table 5) indicate that under natural conditions of development many-flowered racemes form proportionally more pods than do few-flowered racemes. The increase is in regular order until a few more than the medium number of flowers per raceme has been reached, after which the regularity is somewhat broken. This relationship appears in each series, as well as in the average of them all.

Under conditions of artificial tripping the reverse order holds true, or the fewer the number of flowers per raceme, the greater the proportion forming pods. These results do not agree with those of Piper, *et al.*

TABLE 5.—*Average percentage of flowers forming pods on racemes having various numbers of flowers per raceme.*

Number of flowers per raceme	Natural development series			Weighted average	Artificial tripping series			Weighted average
	1	2	3		1	2	3	
	%	%	%	%	%	%	%	%
5 to 11	12.8	21.7	18.6	15.6	43.8	77.4	69.9	69.7
5 to 16	15.3	34.8	33.8	25.7	49.9	73.4	66.3	66.4
12 to 20	21.2	41.1	40.1	34.8	57.3	67.5	67.9	65.2
17 to 32	24.9	42.9	37.8	37.1	55.7	63.5	58.5	59.5
21 to 32	23.2	43.0	35.0	35.6	51.7	63.2	45.0	52.2

DURATION OF STAGES IN DEVELOPMENT OF ALFALFA FLOWERS AS RELATED TO SETTING OF SEED PODS

It has been generally supposed, at least by some alfalfa seed growers of the Uintah Basin, that if a good crop of seed is to result, the changes in development of the flower while forming seed pods should occur in rather rapid succession. In other words, for the flowers to remain in the fresh-looking, full-bloom stage for many days without showing a tendency to wilt, or for them to remain wilted unduly long, are generally considered as conditions not favoring seed production. To gain information on this point the following experiment was conducted.

At four 10-day intervals, while the pods were forming in alfalfa flowers during the season of 1927, flowers were labeled and daily observations made of each individual until it had either formed a pod

or had become stripped. From the study an accurate record was obtained of the individual behavior of 1,191 flowers from the time they had emerged from the bud until they had either formed a pod or had become stripped. Observations were made on these flowers as to just how many of them had formed pods and when the pods were formed. Observations were also made as to just how long each flower had been in the full-bloom stage and in the wilted stage before forming the pods or becoming stripped. The method of procedure in the experiment was as follows.

At the beginning of each 10-day period, except in the last when only 8 were used, 10 representative locations were selected on the plats of the experimental farm. At each location 10 racemes, having the flowers in a condition just ready to expand into full bloom, were selected and numbered with the use of jewelry tags. With a pair of scissors all of the flowers on each raceme, except three or occasionally four, were removed. A drawing was then made to indicate the position of the remaining flowers on the raceme, and for identity each was assigned a number. The flowers were allowed to develop naturally and subsequent examinations were made at intervals of about 24 hours. In making the record of each flower, the letter *f* was placed in a column under the flower number for each day the flower remained in the full-bloom stage. The letter *w* was used in the same way to indicate that the petals had become wilted and continued in this condition. The letter *c* was placed in the column as soon as the flower had formed a seed pod which could be seen emerging from between the petals. The letter *x* was used to indicate that the flower had stripped before forming a seed pod. The observations of each flower ceased as soon as either of the latter two conditions had occurred.

With the record completed, the number of *f's* in the column indicated directly the number of days the flower had been in the full-bloom stage, and the *w's* how many days it had been in a wilted condition before forming a pod or stripping. The position of the *c* or *x* would indicate the date on which the flower formed its seed pod or became stripped.

In Table 6 the data secured have been arranged in a frequency form, in which the full-bloom stage is constant in each class and the duration of the wilted-stage is variable. The results are presented in graphic form to show readily the relative amount of pod-setting and stripping for each variable in the class. The actual percentage of pods formed, based on the total number formed, or 533, is also given in a column to the right. Similarly, the percentage

of flowers stripped, based on the total stripped, or 558, is also given. It will be noted from the total number of flowers forming pods and the total number becoming stripped that the average setting of pods was 44.7%. This average compares favorably with the average for the season, as given in Table 3, and would suggest that the removal of most of the flowers from the racemes did not greatly influence in an abnormal manner the behavior of the remaining few.

The graphic representation indicates that for the 1927 season a period of only one or two days for the flower in the full-bloom stage was most favorable for the setting of pods. The percentage of flowers setting pods decreased on the average for each day after the second until the seventh, when no more pods were formed. A closer study of the lines in the graphic representation shows that within a class where the length of the full-bloom period is the same the flowers remaining only from two to four days in the wilted stage formed the highest percentage of pods. The percentage data also show that on the average during the first two days in full bloom every flower had two chances of forming a pod to one of stripping. On the third day in full bloom the chances were slightly in favor of the flower stripping as against forming a pod. On the fourth day in full bloom the chances became about two in favor of stripping as against one for making a pod. After the fourth day the chances were about equal that the remaining flowers would either strip or form pods.

In Table 7 the same data have been arranged to show the frequency when the length of the wilted stage is constant in a class and the length of the full-bloom stage is the variable. It will readily appear from the length of the dotted lines that during 1927 when the flowers remained in the wilted stage three days the conditions were most favorable for the setting of pods, as is also true for stripping. A period of two days in the wilted stage was equal in value to one of four days, as favoring both pod setting and stripping of flowers. After the fifth day in the wilted condition it appeared to be almost certain that the remaining flowers would strip before they could form pods. During the early part of the full-bloom period the chances on the average were greatly in favor of the flowers forming pods as against stripping. After they had become wilted, the chances of forming pods were on the average never more than equal to those of stripping.

In general, it may be said that when alfalfa flowers on the average are from one to three days in the full-bloom stage and from two to five days in the wilted stage, the chances are greatest that they will

TABLE 6.—*Duration of the full-bloom stage of alfalfa flowers as related to the setting of seed pods (data from a study of 1,191 flowers).*

Stage and duration in number of days[a]		Graphic representation of percentage of pods formed and flowers stripped[b] (1 2 3 4 5 6 7 8 9 10 11 12 13 14)	Pods formed %	Flowers stripped %
1f	1w		0.75	0.71
1f	2w		3.37	2.86
1f	3w		10.88	1.97
1f	4w		8.63	1.25
1f	5w		2.06	2.15
1f	6w		1.87	3.74
1f	7w		0.56	1.79
		Average	4.01	2.06
2f	1w		1.12	2.86
2f	2w		9.00	5.37
2f	3w		12.75	3.22
2f	4w		4.31	2.15
2f	5w		3.56	4.12
2f	6w		1.31	1.25
2f	7w		0.00	0.17
		Average	4.58	2.34
3f	1w		2.06	2.50
3f	2w		3.94	2.68
3f	3w		6.19	6.45
3f	4w		7.31	12.00
3f	5w		0.75	3.22
3f	6w		0.37	0.35
3f	7w		0.00	0.35
		Average	2.94	3.93
4f	1w		1.12	0.35
4f	2w		2.43	1.79
4f	3w		4.55	13.62
4f	4w		1.50	4.48
4f	5w		0.56	0.71
		Average	2.03	4.19

TABLE 6.—*Concluded.*

Stage and duration in number of days[a]		Graphic representation of percentage of pods formed and flowers stripped[b] 1 2 3 4 5 6 7 8 9 10 11 12 13 14		Pods formed	Flowers stripped
5f	1w	— . .		0.18	0.89
5f	2w	————		2.81	4.30
5f	3w	————		3.18	3.04
5f	4w	. .		0.00	0.53
5f	5w	— .		0.18	0.17
			Average	1.27	1.98
6f	1w	— . . .		0.37	1.07
6f	2w	—		0.37	4.12
6f	3w	. .		0.00	0.89
6f	4w	.		0.00	0.35
			Average	0.18	1.60
7f	1w	——		0.56	1.43
7f	2w	—— .		0.75	0.53
7f	3w	—		0.56	0.00
			Average	0.62	0.65
8f	1w	.		0.00	0.17

[a]*w* = wilted stage of flower. *f* = full-bloom stage of flower. Numbers associated with *w* and *f* indicate number of days flower was in the stage designated.

[b]Heavy line (——) indicates extent of pod formation in various stages of flower. Dotted line (. .) indicates extent of stripping in various stages of flower.

form seed pods. On the other hand, if they remain unduly long in either stage without change, the chances are very great that they will fall from the raceme without forming seed pods. The fact may be that these are the days of greatest activity of the flowers, and it is then that they will form their seed pods or fail to function as has been conditioned by the reaction of environment and the inherent nature of the flower.

In conclusion, the results indicated by the data may be said to confirm the opinion of growers that the changes in development of the flower while forming seed pods should occur in rather rapid succession if a good crop of seed is to result. The investigation will be continued until definite conclusions may be drawn upon the problems involved.

TABLE 7.—*Duration of the wilted stage of alfalfa flowers as related to the setting of seed pods (data from a study of 1,191 flowers).*[a]

Stage and duration in number of days		Graphic representation of percentage of pods formed and flowers stripped (1 2 3 4 5 6 7 8 9 10 11 12 13 14)	Pods formed %	Flowers stripped %
1w	1f		0.78	0.76
1w	2f		0.98	3.04
1w	3f		2.16	1.71
1w	4f		1.17	0.19
1w	5f		0.19	1.12
1w	6f		1.37	0.76
1w	7f		0.19	0.93
		Average	0.97	1.07
2w	1f		2.55	2.47
2w	2f		10.20	5.12
2w	3f		2.94	3.42
2w	4f		2.16	1.52
2w	5f		3.12	5.52
2w	6f		0.39	3.61
2w	7f		0.39	1.12
		Average	3.10	3.25
3w	1f		10.85	1.33
3w	2f		11.78	3.23
3w	3f		6.87	7.23
3w	4f		5.10	14.85
3w	5f		3.53	2.85
3w	6f		0.00	1.12
		Average	6.35	5.10
4w	1f		8.84	1.33
4w	2f		4.52	2.09
4w	3f		7.07	11.23
4w	4f		1.57	4.00
4w	5f		0.55	0.57
4w	6f		0.00	0.19
		Average	3.75	3.23
5w	1f		1.76	1.71
5w	2f		4.12	4.57
5w	3f		0.78	3.23
5w	4f		0.55	0.57
5w	5f		0.00	0.38
		Average	**1.44**	**2.08**

TABLE 7.—*Concluded.*

Stage and duration in number of days		Graphic representation of percentage of pods formed and flowers stripped (1 2 3 4 5 6 7 8 9 10 11 12 13 14)	Pods formed %	Flowers stripped %
6w	1f		1.96	4.19
6w	2f		1.37	1.33
6w	3f		0.39	0.19
6w	4f		0.00	0.00
6w	5f		0.19	0.00
		Average	0.78	1.14
7w	1f		0.55	1.33
7w	2f		0.00	0.38
7w	3f		0.00	0.38
		Average	0.18	0.67

[a]See Table 6 for key to symbols.

SUMMARY

1. This paper presents a report of the study of the seasonal behavior of alfalfa flowers as related to seed production.
2. Some stripping of alfalfa flowers is of common occurrence. The pods are also known to strip.
3. Of the 2,042 racemes studied 82.1% possessed pods with mature seed at harvest time.
4. On the average, 34 2% of the flowers on individual racemes formed pods, while the remainder stripped. The percentage of flowers stripping from the individual racemes is proportionally greater and of more consequence from the standpoint of the seed crop than is the complete stripping of flowers from part of the racemes.
5. When the alfalfa flowers were tripped by artificial means, 63.9% formed pods as against 37% when the flowers were allowed to develop naturally.
6. When the flowers were allowed to develop naturally, 10.8% were found to have become tripped, while 37% formed pods. It would seem, therefore, that alfalfa flowers are capable of forming pods rather freely in the absence of tripping.
7. Under natural conditions of development many-flowered racemes formed proportionally more pods than did few-flowered racemes. Under conditions of artifiical tripping the reverse held true.
8. On the average, in general it may be said that when alfalfa flowers are from one to three days in the full-bloom stage and from

two to five days in the wilted stage, the chances are greatest that they will form seed pods. If the flowers remain in the fresh-looking, full-bloom stage for many days without showing a tendency to wilt or if they remain in the wilted condition unduly long the chances are very great that they will strip before forming pods.

THE ADAPTATION OF MEDIUM RED CLOVER STRAINS[1]

A. C. Arny[2]

Importations of red clover seed from Italy have practically ceased since the ruling in September 1926 under the Federal Seed Act, as amended in April of that year, that 10% of all such seed brought in from that country be stained red to indicate that it is not generally adapted for agricultural use in the United States. Each year since staining of imported seed has been compulsory, a large amount of red clover seed has come from French ports. It appears to be highly important to know what the agricultural value of this seed is in the United States, particularly in the states where winterkilling is usually a factor in maintaining stands.

Wiggans (10)[3] reported winterkilling of 95% for stands secured from Italian and 20% and 10%, respectively, for stands secured from French- and Michigan-grown seed. The yields of hay were relative to the stands. From other stands (11) secured from Italian-, French-, and Michigan-grown seed the relative yields were 4, 76, and 100, respectively.

No second cutting was secured by Megee (6) from the stands from Italian seed, and a poor second crop from the stands from French seed, as compared with a good second crop from the stands secured from native-grown seed. Second growth is important for pasture, seed production, and plowing under for green manure.

Cox and Megee (3) estimate that during the five years preceding 1924 from 10 to 15% of the clover seed sown in Michigan came from Italy or other Mediterranean regions. They say, "These experiments and similar ones in other northern states prove conclusively that clover seed must be distributed according to its adaptation— that seed produced under mild climatic conditions is not adapted to Michigan or other northern and corn belt states. Northern grown domestic seed should be used." Alsike, sweet clover, alfalfa, or soybeans are advised for use in Michigan when adapted domestic seed is not available.

In Indiana Christie (2) reports winterkilling of 82, 68, and 67%, respectively, for stands from three strains of Italian red clover, and 23, 25, 30, and 36% from four French strains as compared with no killing in stands from native strains.

[1]Contribution from the Division of Farm Management, Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St. Paul, Minn. Published with the approval of the Director as Paper No. 771 of the Journal Series. Received for publication March 12, 1928.

[2]Professor of Agronomy and Head of the Section of Farm Crops.

[3]Reference by number is to "Literature Cited," p. 567.

Data presented by Pieters (8) show that Italian, French, and Chilean red clover seed is not suitable for use in the states with severe winters. In another publication Pieters (9) mentions that seed from Italy will not usually live through winters in the Ohio River Valley unless covered with snow. In that section stands secured from French or Chilean seed lived through the winter better but produced lower yields, particularly in the second crop.

In Minnesota, Arny (1) found that stands from seed from France, Chile, and Italy winterkilled 81.4, 89.5, and 93.8%, respectively. While there was slightly less winterkilling of the plants from the French seed than from the other two, crop failures resulted from the use of seed from these sources as compared with yields of 1.35 and 1.40 tons per acre from the stands from native seed and 1.54 tons per acre from stands from strains from northern Europe.

McRostie (7) states that all Italian red clover seed is unsafe for planting in Canada. Of the lots of seed imported from France only about one-fifth could be classed as reasonably safe to use and the plants from the other four-fifths were definitely non-hardy.

For use in Virginia, Wolfe and Kipps (12) found red clover stands from anthracnose-resistant strains persisted longer and gave higher total yields of hay than stands from non-resistant strains. Over a period of four years, Italian seed gave the poorest results and seed from France was decidedly less satisfactory than seed from Ohio, Tennessee, Michigan, and Wisconsin.

From results in Wisconsin covering a period of five years, Delwiche (5) concludes that foreign-grown red clover seed should not be used in Wisconsin. At the Spooner branch station severe winterkilling occurred three years out of five and at the Ashland and Marshfield stations two years out of three. In addition to the undesirability of foreign red clovers from the standpoint of winterkilling, they were found to contain noxious weeds.

From the results of trials extending over a period of years, Curtis (4) found that no imported clover seed was satisfactory in Iowa except that from Canada.

RESULTS OF WORK IN MINNESOTA

Seed was furnished by A. J. Pieters, in Charge of Clover Investigations, Forage Crop Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, as part of the cooperative work. Seed of the Minnesota- and Wisconsin-grown strains was secured direct.

METHODS OF CONDUCTING THE WORK

The clovers were sown in 1922 and 1923 on triplicate plats 5 feet wide and 132 feet long with alleys 1 foot wide between each two plats. In 1926 the seedings were made in duplicate only. In 1922 oats was used as a companion crop, while in 1923 and 1926 no companion crop was used. The seed was evenly distributed on each plat by hand at the rate of 12 pounds of good seed per acre. The plats were then harrowed lengthwise to cover. In 1922 good stands were secured of all strains except that from Wisconsin. The stand for that strain averaged 82.5%. Red clover seed from Wisconsin is the equal in every respect to seed secured from other northern states, but this particular sample was low in germination. In 1923 continued dry weather prevailed for a period after the seeding was done and as a result very unsatisfactory stands were secured. However, there were consistent differences in the stands obtained on the three plats of each strain. The best stand was from native alsike. The strains of medium red clover from Jugoslavia, Bohemia, and Austria produced better stands than any of the native strains. This indicates that there may be differences in the ability of the seedlings of the various strains to establish themselves under unfavorable conditions as to moisture.

Dry weather prevailed in 1926 up to June and slow growth was made up to that time. Ample rains in June and the months following resulted in good stands from all the strains as shown by a check in the autumn.

Survival during the winter of 1926-27 of the plants of the strains low in cold resistance was largely a matter of snow cover. The series on which the plats were located extends north and south and slopes off at each side for a distance of approximately 10 to 15 feet on each side. The west and northwest winds blew the snow off of much of the central portion of the series and deposited considerable amounts of it on the lower portions and on the adjoining roads. The plants of the hardy strains persisted whether they were covered with snow or not, while the somewhat less hardy strains showed winterkilling to a greater or less degree where the snow was blown off. The strains largely lacking in hardiness killed out completely except where they were covered with snow throughout the winter.

The entire product of each plat was weighed as soon as cut and shrinkage samples for dry matter determination taken. Probable error for the yields on the 15% moisture basis was calculated by the deviation from the average method. Differences in yield in pounds per acre with odds of 31 to 1 are 462.9 for the first cutting, 411.2 for the second cutting, and 443.2 for the total of the two cuttings.

WEATHER FOR WINTER OF 1926–27

The winter of 1926–27 was somewhat more mild than the average. No temperatures lower than —19°F were recorded. There was a minimum temperature on March 19 of 15° and one on March 27 of 19°F, but no extended freezing weather. In April no temperatures low enough to kill clover plants in an active condition occurred. The minimum temperatures are given in Table 1.

TABLE 1.—*Maximum and minimum temperatures, together with total precipitation and precipitation as snow from October 1, 1926, to April 30, 1927, at University Farm, St. Paul, Minn.*[a]

Month	Maximum temperature recorded	Number of days with minimum temperature, October 1 to April 30: 33° or above	32° to 23°	22° to 13°	12° to 1°	0° to –6°	-7° to –12°	–13° to –18°	Below –18°	Lowest temperature recorded	Precipitation: Total inches	As snow, inches
October....	72°	25	6	0	0	0	0	0	0	23°	2.35	1.9
November	59°	4	10	5	11	0	0	0	0	8°	2.12	8.2
December.	38°	0	2	10	8	5	3	3	0	—18°	1.73	10.6
January....	42°	0	4	6	7	5	6	2	1	—19°	0.68	2.1
February...	48°	1	4	13	5	4	1	0	0	—10°	0.28	6.8
March......	67°	11	13	5	2	0	0	0	0	11°	2.07	8.0
April.......	77°	25	5	0	0	0	0	0	0	24°	2.16	1.7

[a]Temperatures expressed as degrees F.

TABLE 2.—*Comparison of the percentage winterkilling and yields per acre at University Farm, St. Paul, Minn., in 1927 from stands of medium red clover from the leading seed-producing areas of the world.*

Source	Strain No.	Plat No.	Winter-killing %	Yields in pounds per acre on a 15% moisture basis: First	Second	Total	Percentage yields with Minn. medium as 100: First	Second	Total	Yield second crop as percentage of first crop
I. Strains from North Central and North Inter-mountain States										
Minnesota	—	2–40	8.24	4,579	920	5,499	100.0	100.0	100.0	16.7
Michigan	2570	8–46	10 6	3,383	1,700	5,083	73.9	184.8	92.4	41.9
Wisconsin	—	10–48	58.8	4,080	960	5,040	89.1	104.4	91.7	23.5
Canada	2647	12–50	49.4	2,560	630	3,190	59.9	68.5	58.0	24.6
Idaho	2586	16–54	31.8	3,420	1,280	4,700	74.7	139.2	75.5	37.4
North Dakota	2511	18–56	21.2	4,250	1,630	5,880	92.8	171.2	106.9	38.4
South Dakota	2473	20–58	8.2	4,490	1,300	5,790	98.1	141.3	105.3	29.0
Average			26.9	3,823	1,203	5,026	84.1	130.8	89.9	30.2

TABLE 2.—*Concluded*

Source	Strain No.	Plat No.	Win-ter-killing	Yields in pounds per acre on a 15% moisture basis			Percentage yields with Minn. med'um as 100			Yield second crop as percentage of first crop
			%	First	Second	Total	First	Second	Total	
II. Strains from North and South Central, South Atlantic, and North Pacific Coast States										
Tennessee	2469	14–52	36.5	3,020	1,600	4,620	66.0	173.9	84.0	53.0
Illinois	2573	21–59	16.5	3,840	1,540	5,380	83.9	167.4	97.8	40.1
Virginia	2545	22–60	14.1	4,130	1,440	5,570	90.2	156.5	101.3	34.9
Ohio	2582	23–61	38.8	3,070	1,240	4,310	67.0	134.8	78.4	40.4
Oregon	2587	24–62	33.9	3,230	1,280	4,510	70.5	139.1	82.0	39.6
Oregon	2474	25–63	47.1	2,140	870	3,010	46.7	94.6	54.7	40.7
Average			31.2	3,238	1,328	4,566	70.7	144.4	83.0	41.4
III. Strains from Central Europe										
Poland	2543	30–68	36.5	3,450	870	4,320	75.3	62.0	78.6	25.2
Poland	2544	31–69	25.9	3,570	850	4,420	78.0	92.4	80.4	23.8
Poland	65965	32–70	22.4	3,640	1,050	4,690	79.5	114.1	85.3	28.9
Poland	58858	38–76	54.1	3,150	640	3,790	68.8	69.6	68.9	20.3
Poland	61354	4–42	63.5	2,060	680	2,740	45.0	73.9	49.8	33.0
Germany	2514	26–64	45.9	2,680	920	3,600	58.5	100.0	66.5	34.3
Roumania	2423	28–66	48.2	2,730	950	3,680	59.6	103.3	66.9	34.8
Roumania	2516	29–67	52.9	2,360	880	3,240	51.5	95.7	58.9	37.3
Hungary	2413	33–71	54.1	2,130	660	2,790	46.5	71.7	50.7	31.0
Hungary	2508	34–72	55.3	2,260	560	2,820	49.4	60.9	51.3	25.2
Hungary	2415	35–73	63.5	1,670	540	2,210	36.5	58.7	40.2	32.3
Czechoslovakia ...	61383	36–74	49.2	2,190	720	2,910	47.8	78.3	52.9	32.9
Czechoslovakia	61381	37–75	51.8	2,410	730	3,140	52.6	79.4	57.1	30.3
Average			47.9	2,638	773	3,412	57.6	81.5	62.0	29.9
IV. Strains from France, Italy, Chile, and England										
Italy	2397	3–41	97.7	587	420	1,007	12.8	45.7	18.3	65.6
France	2636	5–43	87.1	699	320	1,019	15.3	34.8	18.5	38.1
France	2635	7–45	78.8	1,114	720	1,834	24.3	78.3	33.4	53.7
France	2509	9–47	75.3	1,032	540	1,572	22.5	58.7	28.6	81.8
France	2634	11–49	90.6	680	350	1,030	14.9	38.0	18.7	51.5
France	2411	13–51	90.6	650	380	1,030	14.2	41.3	18.7	58.5
Chile	2658	15–53	81.2	1,260	640	1,900	27.5	59.6	34.6	50.8
Chile	2403	17–55	77.7	1,400	610	2,010	30.6	66.3	36.6	43.6
Chile	239913	19–57	78.8	1,080	330	1,410	23.6	35.9	25.6	30.6
England	2554	27–65	74.1	1,230	640	1,870	26.9	69.6	34.1	52.0
Average			83.4	973	495	1,468	21.3	52.8	26.7	52.6

The ground remained frozen throughout the winter up to the early part of March and for the most part was snow covered except as the snow was blown off on the parts slightly more elevated than others.

The rainfall during the summer was favorable for a good yield of hay from both the first and second cuttings.

RESULTS OF THE TESTS

In Table 2 are given the results for the strains of medium red clover in 1927. In this table the grouping of the strains is based on geographical relationship and similarity of climate of the states or countries from which the seed was secured.

The plat numbers are given for each strain in order to show the arrangement in the field. Minnesota-grown alsike grew on plats 1 and 39 and Minnesota-grown mammoth red clover on plats 6 and 44. Alternated with the northern-grown strains in the even-numbered plats were grown the strains from Italy, France, and Chile on the odd-numbered plats. This arrangement was followed in order to make the conditions as nearly alike as possible for both the hardy and tender strains.

Seed of the Wisconsin strain was secured from the experiment station at Madison and the seed of the Canadian strain was furnished with the majority of the others. The winterkilling for both of these strains appears high but results on duplicate plats checked fairly well. The yield from the Wisconsin strain was exceptionally good considering the amount of winterkilling that took place. Both of the Dakota strains and the Minnesota-grown mammoth, which is not included in the table, yielded slightly but not significantly higher than Minnesota-grown medium red. Alsike yielded 73.9% as high as the Minnesota-grown medium.

The group of native strains from the states with milder climates than those of group I averaged only slightly higher in winterkilling but significantly lower in yield than the northern-grown strains in the first cutting and the total yield. The strain from Virginia came through the winter in as good shape and produced a slightly higher total yield than the Minnesota-grown strain. Strain No. 2474 from Oregon was decidedly less desirable than the other strain from the same state.

The plants of the strains in group II were similar in appearance to those of the strains in group I. This indicates similar origin. As far as winter hardiness of these red clover strains is concerned the source of the original seed appears to be of first importance.

On the average, the strains from central Europe winterkilled more and yielded significantly less for each cutting than the native strains.

Three of the five strains from Poland yielded well but significantly lower than the average for the northern-grown native strains. The strains from Germany, Roumania, Hungary, and Czechoslovakia winterkilled about as high a percentage and yielded at about the same rate as the two less desirable strains from Poland. All of these strains were much more susceptible to clover diseases, particularly in the second crop, than the native strains.

In group IV the results from the strains from southern Europe, Chile, and England are given. The winterkilling was so high in the stands from these strains that the yields were very materially lowered. For the two cuttings the Italian strain yielded 18.3% of the yield of the Minnesota-grown strain. Two of the French strains were somewhat higher in yield than the Italian strain and three others yielded at about the same rate as the Italian strain.

The strains from Chile and England yielded at about the same rate as the two highest yielding strains from France or about one-third the crop produced by the Minnesota-grown strain.

YIELDS FROM THE SECOND CROP IN 1927

In group I the percentage the second crop was of the first crop varied from 16.7 for the Minnesota strain to 41.9 for the Michigan strain with an average for the seven strains of 30.2. The Michigan and North Dakota strains were high in yield of the second crop.

In group No. 2 the yields of the first crop averaged significantly lower than the first crop for group I and the second crop averaged somewhat higher. This makes the relation of the average yield for the second crop 41.4% of the average yields of the first crop, or 11.2% higher than for group I. Disease did not appear to be a factor in either the first or the second crops of the strains in these two groups.

In group III, although both the first and second crops were considerably lower than for group I, the relation of the yield of the second to the first crop is about the same. In this group of strains the growth made by the second crop was small. This was due in part at least to injury by diseases. The second crop from the strains from Italy, France, Chile, and England averaged less than half that of the second crop from the two groups of native strains. Although the yields of the second crop from the strains in this group were exceedingly small, they averaged 52.6% of the yields from the first crop. The yields of the second crop of all of these strains were reduced materially by disease injury.

NORTHERN-GROWN NATIVE STRAINS AVERAGE HIGHEST YIELDS

In Table 3 the average percentage of winterkilling, the average yields for the first and second cuttings, and the total yields for each of the four groups as given in Table 2 have been assembled. Several strains were grown from each of a number of the European countries and from Chile. The yields from the strains coming from each country have been averaged and are included in the table so that comparisons may be made readily. The relative yields for each crop and the total with the average for the northern-grown native strains considered as 100 were computed and are given in this table.

TABLE 3.—*Comparison of actual and relative percentages of winterkilling and yields per acre of strains of medium red clover from the seed-producing countries of the world for 1927 at University Farm, St. Paul, Minn.*

Sources of seed	Winter killing	Yields in pounds per acre on a 15% moisture basis			Percentage yields with northern-grown native strains as 100		
	%	First	Second	Total	First	Second	Total
Native Strains							
I. Northern grown	26.9	3,823	1,203	5,026	100.0	100.0	100.0
II. Central, southern, and western	31.2	3,238	1,328	4,566	84.7	110.4	90.8
Foreign Strains							
III. Western or central continental Europe	49.0	2,544	793	3,337	66.5	65.9	66.4
Poland	40.5	3,174	818	3,992	83.0	68.0	79.4
Roumania	50.0	2,545	915	3,460	66.6	76.1	68.8
Hungary	57.6	2,020	587	2,607	52.8	48.8	51.9
Chechoslavakia	50.5	2,300	725	3,025	60.2	60.3	60.2
Germany	49.5	2,680	920	3,600	70.1	76.5	71.6
IV. Southern continental Europe, England, and Chile	83.9	975	512	1,488	25.5	42.6	29.6
France	84.5	835	462	1,297	21.8	38.4	25.8
Italy	97.7	587	420	1,007	15.4	34.9	20.0
England	74.1	1,230	640	1,870	32.2	53.2	37.2
Chile	79.2	1,247	527	1,773	32.6	43.8	35.3

Computed from the average yields of the native-grown strains as 100, the strains from Ohio, Illinois, Virginia, Tennessee, and Orgeon averaged 84.7% for the first, 110.4% for the second, and 90.8% for the total crop.

The strains from western and central continental Europe averaged 66.5% for the first, 65.9% for the second, and 66.4% for the total crop of the yields of the northern-grown native strains. The strains from Poland yielded considerably above the average and those from Hungary below the average for the group.

Compared with the average yields from the native northern-grown strains the yields from the strains from France, Italy, England, and Chile averaged 25.5% for the first, 42.6% for the second, and 29.6% for the total crop. The yields from the strains from England and Chile were somewhat above and the strains from France and Italy were lower than the average for the group.

YIELDS FOR 1923

The yields secured from the different strains in 1923 were published in a previous article (1). A summary of these yields is included in Table 4.

Lower yields were secured from the first cuttings in 1923 than in 1927. Of the native strains the group from the central, southern, and western locations somewhat more clearly approached the northern-grown group in total yield than in 1927. As in 1927, the central, southern, and western group averaged somewhat higher in yield of the second crop than the northern-grown strains.

TABLE 4.—*Comparison of actual and relative percentages of winterkilling and yields per acre of strains of medium red clover from the seed-producing countries of the world for 1923 at University Farm, St. Paul, Minn.*

Source of seed	Winter killing	Yields in pounds per acre on a 15% moisture basis			Percentage yields with northern-grown native strains as 100		
	%	First	Second	Total	First	Second	Total
Native Strains							
I. Northern grown	9.2	1,900	1,040	2,940	100.0	100.0	100.0
II. Central, southern, and western	23.4	1,580	1,200	2,780	83.2	115.4	94.5
Foreign Strains							
III. Western and central continental Europe and Australia	43.0	1,810	1,026	2,833	95.3	98.7	96.4
Poland	18.8	1,960	1,026	2,980	103.2	98.7	101.4
Bohemia	38.8	2,360	1,100	3,460	124.2	105.8	117.7
Germany	37.4	1,760	1,140	2,900	92.6	109.6	98.6
Holland	53.6	1,380	700	2,080	72.6	67.3	70.7
Hungary	57.7	1,660	1,160	2,820	87.4	111.5	95.9
Australia	51.7	1,740	1,029	2,760	91.6	98.1	93.9
IV. South continental Europe, Wales, and Chile							
France	81.2	—	—	—	—	—	—
Italy	93.8	—	—	—	—	—	—
Wales	83.2	—	—	—	—	—	—
Chile	89.5	—	—	—	—	—	—

The group of strains from western and central continental Europe and Australia averaged well up with the native northern-grown strains in yields from both cuttings and total yields. The yield from the second crop of the Polish strain is not available; but since the notes taken on the crop indicate that it was fair, the average for the group has been taken as the yield for the second crop of this variety. The strains from Bohemia were particularly high in yield and that from Holland lower than the average for the group.

No yields were taken from the strains from France, Italy, Wales, and Chile due to the very high percentages of winterkilling.

RESULTS FOR THE 1923 AND 1927 TESTS

While the strains in each group varied somewhat for the two years, the average results are very similar. Therefore, the results for each group for the two-year period have been averaged and are given in Table 5.

TABLE 5.—*Two-year average of the actual and relative percentages of winterkilling and yields per acre of strains of medium red clover from the seed-producing countries of the world for 1923 and 1927, University Farm, St. Paul, Minn.*

Sources of seed	Loss in stand	Yields in pounds per acre on a 15% moisture basis			Percentage yields with northern-grown native strains as 100		
	%	First	Second	Total	First	Second	Total
Native Strains							
I. Northern grown	18.1	2,862	1,122	3,983	100.0	100.0	100.0
II. Central, southern, and western grown	27.3	2,409	1,264	3,673	84.2	126.6	92.2
Foreign Strains							
III. Western and central continental Europe	21.3	2,228	1,016	3,244	77.8	91.4	81.4
IV. Southern continental Europe, England, Wales, and Chile	85.4	488	256	744	17.0	22.8	18.7

For the two tests the average yield from the first cutting of the strains from central, southern, and western United States was significantly lower than the average for the native strains. However, the average for the second cutting was 26.6% higher than the average for the northern-grown native strains.

Both the first and second cuttings from the strains coming from western and central continental Europe were lower than the yields from the two groups of native strains. The average total yield from this group was 81.4% of that secured from the northern-grown native strains.

The strains from southern continental Europe, England, Wales, and Chile averaged 85.4% winterkilling. As a result of the high percentage of winterkilling and injury by disease the total yield from strains in this group averaged only 18.7% of the average yield from the native northern-grown strains.

SUMMARY AND CONCLUSIONS

From the results of these tests it is evident that medium red clover seed from France, Chile, and Italy is of no value for seeding in Minnesota. In adjoining states and provinces of similar climatic conditions like results are to be expected. Results of experimental tests in Iowa, Wisconsin, and Canada show that this is the case.

These results show conclusively that red clover seed from France and Chile, as well as that from Italy, is not generally adapted for agricultural use in the United States. At present the regulation requiring the staining of Italian red clover seed 10% red is practically inoperative due to the fact that much of the surplus Italian seed probably comes through the ports of France as French seed. Since French and Chilean red clover seed is in the same class as Italian seed as far as use in the North central states is concerned, regulations are needed under the Federal Seed Act to stain this seed red to distinguish it from the seed actually produced in north central continental Europe.

The Dakotas, Iowa, Wisconsin, and Minnesota use more clover seed than they produce. Until such time as staining 10% red of all French and Chilean red clover seed brought into this country is compulsory, farmers cannot afford to sow any imported seed of this crop except that from Canada which is stained 10% iridescent violet. The seeding down of larger acreages of sweet clover and hardy alfalfa is preferable to the use of non-hardy, imported red clover as mixtures in native-grown seed.

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CORRECTING YIELDS IN ROD-ROW TRIALS WITH THE AID OF THE REGRESSION EQUATION[1]

Fred Griffee[2]

The fact of soil variation is generally recognized and usually in experimental work more or less consideration is given to methods of reducing the error due to chance differences in soil. Some measure of variability, such as probable error or standard deviation, is used as an index of the accuracy of the experiment. The greater the probable error the more variation there is supposed to be and, in a comparison of varieties, the greater the differences must be in order to be of significance. If some means are available whereby the probable error can be reduced, the actual differences between varieties or strains may assume greater significance.

The method applied to rod-row trials by Hayes[3] is applicable to experiments in which systematic replication is used. This method consists of placing all the plats in the field on a percentage basis by dividing each plat of a variety by the average for that variety. By this method, the relative yielding ability of each plat is obtained. Correlation coefficients are then obtained for adjacent plats and for plats various distances apart. The regression equations also are calculated for these same plats. The percentage yield of each check is obtained by dividing its yield by the average yield of all the checks and multiplying by 100. The yielding ability of any plat is then obtained on a percentage basis by averaging the values for "$\bar{y}$" of the checks on either side of that particular plat. Corrected yields are obtained by dividing the actual yield by the corrected percentage yield and multiplying by 100. Hayes found that the probable erorrs were reduced slightly by application of this method, although hardly enough to warrant the extra work exacted. The method, however, possesses some merits and may prove of considerable value under certain conditions.

Due to the fact that the probable errors in the rod-row trials for winter wheat at this station in 1927 were extremely high, the results offered excellent material to try Hayes' method under conditions of a highly variable soil.

[1]Contribution from the Department of Field Crops and Soils, Oklahoma Agricultural and Mechanical College, Stillwater, Okla. Published with the approval of the Director of the Experiment Station. Received for publication March 16, 1928.

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[3]Hayes, H. K. Control of soil heterogeneity and the use of the probable error concept in plant breeding studies. Minn. Agr. Exp. Sta. Tech. Bul. 30. 1925.

CORRELATION OF YIELDING ABILITY OF ADJACENT AND NEARBY PLATS IN WHEAT ROD-ROWS

At the time of planting in the fall of 1926, the field selected for the rod-row trials appeared ordinarily uniform. It was rented land, however, and although in use by the experiment station for two years, little is known about the cropping system used previous to 1926. At the time the wheat was heading, distinct differences could be seen in the field. There appeared to be a progressive decrease in yielding value of the plats from north to south.

There were 199 varieties in the test mostly in single-row plats. Check plats, of three rows each, were planted every tenth plat for single-row plats and every fourth plat for three-row plats. In the three-row plats, as is the custom, only the central rows were harvested for yield. This arrangement made the check plats 12 feet apart through the entire experimental area. Each variety or strain was replicated three times making four plats of each. The rows were planted in a north and south direction.

The yields of the checks are given in Table 1 on a percentage basis considering the average of all the checks as 100%. The averages of the checks were determined across the series and across the field from north to south in order to learn if the change in soil was uniform in one direction.

TABLE 1.—*Yields of check plats expressed in percentage of the average of all checks*

Series No.					North						Average
1	212	116	112	160	180	124	84	88	172	96 4	134.4
2	88	140	148	144	112	168	124	168	172	152	141.6
3	124	96	108	108	112	172	100	120	108	152	120.0
4	156	112	100	112	168	180	120	120	120	92	128.0
5 West	76	152	192	108	100	152	124	140	152	120	131.6 East
6	144	56	64	72	80	168	60	76	172	48	94.0
7	72	52	68	96	96	144	212	100	116	64	102.0
8	40	92	96	44	116	52	60	48	120	88	75.6
9	56	60	40	24	44	20	16	40	56	52	40.8
10	88	40	44	48	56	52	56	40	116	76	61.6
11		60	28	28	60	56	68	64	48	36	49.8
Average	105.6	88.7	90.9	85.8	102.2	117.7	93.1	91.3	122.9	88.7	
					South						

Series No. 11 was decidedly lower in yield than series No. 1, but the change was not uniform from north to south. Neither is the change in yielding ability progressive. Series No. 2 is highest in yield, series No. 1 is second, and series No. 5 is third. The field seemed less variable from east to west, but the variation was neither

uniform nor progressive. Correction directly on the basis of check plats, therefore, was not desirable.

The probable error of the experiment for all varieties was 13.7% as determined by the deviation from the mean method.[4] The soft wheats in general yielded about four times as much as the hard wheats, due very largely, no doubt, to a heavy epidemic of leaf rust. The soft wheats, as a group, showed more resistance to leaf rust than the hard wheats, although there were a few notable exceptions. As it is unfair in using probable errors to lump together varieties differing widely in yield, it seemed wise to calculate two probable errors. The division line was made at 7.0 bushels per acre. The probable error for 84 varieties yielding 7.0 bushels or better is 8.91%, while for the other 115 varieties which yielded less than 7.0 bushels per acre the probable error is 16.34%. The latter probable error compares with that obtained from the use of the checks, 14.6%. These probable errors are rather high with the possible exception of the one for wheats yielding 7.0 bushels per acre or better.

Correlation coefficients were calculated for plats 2, 3, 4, 5, 6, 7, 8, 9, and 10 feet apart, respectively. These, together with standard deviations, means, and regression equations, are given in Table 2.

The correlation coefficient for plats 2 feet apart was 0.695 ± .015 and was approximately the same for plats 3, 4, and 5 feet apart, respectively. It dropped off to 0.611 ± .019 for plats 10 feet apart.

Corrected yields were obtained by the same method as used by Hayes except the regression was used for X on Y instead of Y on X for the second check. This may be illustrated as follows:

	Row No.	Percentage yield Actual	Percentage yield Corrected	Yield, bushels per acre Actual	Yield, bushels per acre Corrected
Check	2	96		2.4	
Fultz	4	122	120	10.9	9.1
Check	14	172		4.3	

For plat 4, which was 2 feet from check 2 and 10 feet from check 14, the corrected percentage would be:

$$\bar{Y} = 29.74 + 0.7021x = 29.74 + 0.7021 \times 96 = 97$$

$$\bar{X} = 41.00 + 0.5917y = 41.00 + 0.5917 \times 172 = 143$$

Corrected percentage yield of plat 4 = Ave. = 120

The actual yield of plat 4 (10.9) divided by 120 and multiplied by 100 = 9.1 bushels, which is the corrected yield.

The yields of all varieties before and after correction are given in Table 3, together with the ranking of each variety before and after correction.

[4]See footnote 3.

TABLE 2.—*Correlation of percentage yielding ability in plats of wheat rod-rows in 1927.*

Correlation of plats	Correlation coefficient	Means X	Means Y	Standard deviation X	Standard deviation Y	Regression equations	
2 feet apart	0.695±.015	99.53	99.62	40.19	40.60	$\bar{Y}=29.74+.7021x$	$\bar{X}=30.99+.6880y$
3 feet apart	0.707±.015	99.20	99.36	39.82	39.86	$\bar{Y}=29.16+.7077x$	$\bar{X}=29.02+.7063y$
4 feet apart	0.698±.016	99.73	100.21	40.63	40.29	$\bar{Y}=31.18+.6922x$	$\bar{X}=29.19+.7039y$
5 feet apart	0.680±.017	100.02	100.27	40.46	40.70	$\bar{Y}=31.86+.6840x$	$\bar{X}=32.24+.6760y$
6 feet apart	0.640±.018	100.15	100.51	41.39	41.78	$\bar{Y}=35.81+.6460x$	$\bar{X}=36.43+.6340y$
7 feet apart	0.626±.020	100.63	100.74	40.11	41.62	$\bar{Y}=35.37+.6496x$	$\bar{X}=39.85+.6033y$
8 feet apart	0.619±.020	100.09	100 96	40.14	42.34	$\bar{Y}=35.61+.6529x$	$\bar{X}=40.85+.5868y$
9 feet apart	0.654±.018	100.26	100.57	38.88	40.57	$\bar{Y}=32.15+.6824x$	$\bar{X}=37.22+.6268y$
10 feet apart	0.611±.019	100.60	100.72	39.50	40.79	$\bar{Y}=37.24+.6310x$	$\bar{X}=41.00+.5917y$

TABLE 3.—*Comparison of the yields of varieties and strains before and after correction by the use of checks and regression.*

Variety	Row No.	Yield Before correction	Yield After correction	Placing Before correction	Placing After correction	Difference, actual—corrected
Fulcaster	179	17.0	17.2	1	1	—0.2
Malakov	95	16.6	15.6	2	3	+1.0
Indiana Swamp	202	16.5	16.2	3	2	+0.3
Fulcaster	154	15.1	14.9	4	6	+0.2
Fulcaster	167	15.0	15.4	5	4	—0.4
Fulcaster	163	13.7	14.1	6	11	—0.4
Fultz	52	13.1	12.8	7	18	+0.3
Mediterranean	226	12.5	14.2	8	10	—1.7
Fulcaster	188	12.4	12.5	9	24	—0.1
Fultz	41	11.8	15.4	10	5	—3.6
Fultz	40	11.8	14.8	11	7	—3.0
Fulcaster	162	11.7	11.8	12	31	—0.1
Fultz	46	11.7	14.4	13	8	—2.7
Fultz	19	11.7	12.9	14	17	—1.2
Fultz	17	11.4	12.8	15	19	—0.6
Fultz	45	11.3	13.7	16	13	—2.4
Fultz	239	11.1	12.4	17	28	—1.3
Fultz	55	11.1	11 0	18	37	+0.1
Fulcaster	189	10.9	10.8	19	40	+0.1
Fultz	34	10.9	14.3	20	9	—3.4
Fulcaster	164	10.8	10.6	21	43	+0.2
Fultz	54	10.8	10.5	22	48	+0.3
Fultz	56	10.7	10.6	23	44	+0.1
Fultz	16	10.6	11.2	24	36	—0.6
Fulcaster	173	10.5	10.6	25	45	—0.1
Fultz	47	10.5	12.6	26	22	—2.1
Fultz	43	10.5	12.6	27	23	—2.1
Fultz	42	10.5	12.8	28	20	—2.3
Fultz	29	10.5	13.5	29	14	—3.0
Fultz	6	10.5	10.7	30	41	—0.2
Fultz	33	10.4	13.9	31	12	—3.5
Fultz	11	10.4	9.9	32	54	+0.5
Fultz	22	10.3	11.5	33	35	—1.2
Fulcaster	190	10.2	12.5	34	25	—2.3
Fultz	44	10.2	12.1	35	29	—1.9
Fultz	31	10.2	13.2	36	16	—3.0
Fultz	28	10.2	12.8	37	21	—2.6
Fultz	23	10.2	12.0	38	30	—1.8
Fultz	20	10.2	11.0	39	38	—0.8
P1066 X Marquis	192	10.1	10.1	40	52	0.0
Fultz	30	10.1	13.3	41	15	—3.2
Fultz	12	10.1	10.2	42	50	—0.1
Malakov	101	10.0	8.3	43	76	+1.7
Fultz	58	10.0	10.3	44	49	—0.1

TABLE 3 —*Continued.*

Variety	Row No.	Yield Before correction	Yield After correction	Placing Before correction	Placing After correction	Difference, actual—corrected
Fultz	57	10.0	10.7	45	42	—0.7
Fultz	18	10.0	11.6	46	32	—1.6
Fultz	9	10.0	10.0	47	53	0.0
Fultz	36	9.9	12.5	48	26	—2.6
Fultz	53	9.6	9.4	49	58	+0.2
Fultz	24	9.6	10.6	50	46	—1.0
Miracle	221	9.5	10.9	51	39	—1.4
Fultz	8	9.5	9.3	52	60	+0.2
Fultz	32	9.4	12.5	53	27	—3.1
Malakov	59	9.3	9.4	54	59	—0.1
Miracle	213	9.2	9.0	55	63	+0.2
Fulcaster	153	9.2	9.2	56	61	0.0
Mich. Wonder No. 21	232	9.1	9.8	57	56	—0.7
Fultz	48	9.1	10.6	58	47	—1.5
Fulcaster	177	9.0	9.0	59	64	0.0
Fultz	10	9.0	8.7	60	71	+0.3
Fultz	5	9.0	8.8	61	68	+0.2
Kanred X Marquis	196	8.9	8.4	62	73	+0.5
Fultz	4	8.9	8.7	63	72	+0.2
Mich. Amber	308	8.8	11.6	64	33	—2.8
Mich. Wonder No. 8	228	8.8	9.7	65	57	—0.9
Miracle	214	8.8	8.8	66	69	0.0
Miracle	212	8.8	8.9	67	66	—0.1
Tenmarq	201	8.8	8.4	68	74	+0.4
Fultz	35	8.8	11.6	69	34	—2.8
Miracle	215	8.6	8.4	70	75	+0 2
Sibleys New Golden No. 81	275	8.3	10.2	71	51	—1.9
Miracle	223	8.2	9.0	72	65	--0.8
Fultz	21	8.1	9.1	73	62	—1.0
Miracle	245	8.0	7.4	74	83	+0.6
Miracle	222	7.9	8.9	75	67	—1.0
Miracle	216	7.7	7.7	76	80	0.0
Fulcaster	155	7.6	7.9	77	79	—0.3
Malakov	96	7.5	6.7	78	86	+0.8
Blackhull	311	7.3	9.9	79	55	—2.6
Beechwood Hybrid	269	7.3	8.8	80	70	—1.5
Miracle	220	7.2	8.1	81	78	—0.9
Fulcaster	224	7.0	8.2	82	77	—1.2
Fulcaster	185	7.0	7.5	83	82	—0.5
Fulcaster	165	7.0	7.0	84	85	0.0
Kanred X Marquis	197	6.8	6.4	85	87	+0.4
Fulcaster	227	6.5	7.4	86	84	—0.9
Fulcaster	156	6.5	6.3	87	89	+0.2

TABLE 3—*Continued.*

Variety	Row No.	Yield Before correction	Yield After correction	Placing Before correction	Placing After correction	Difference, actual—corrected
Fulcaster	180	6.4	6.3	88	90	+0.1
P1066 X Marquis	209	6.3	5.9	89	94	+0.4
Turkey	139	6.2	5.5	90	102	+0.7
Turkey	127	6.2	5.7	91	99	+0.5
Malakov	67	6.2	5.5	92	103	+0.7
Mediterranean	251	6.1	5.6	93	100	+0.5
Turkey	129	6.0	5.4	94	105	+0.6
Harvest Queen	305	5.9	7.6	95	81	—1.7
Marquis X Kanred	203	5.9	6.4	96	88	—0.5
Turkey	132	5.9	5.2	97	109	+0.7
Turkey	128	5.9	5.4	98	106	+0.5
Miracle	263	5.8	6.1	99	91	—0.3
Fultz	7	5.8	5.9	100	95	—0.1
11-C-1-A	260	5.7	5.8	101	97	—0.1
Fulcaster	178	5 7	5.6	102	101	+0.1
Currell	299	5.6	6.0	103	93	—0.4
Turkey	126	5.6	5.1	104	113	+0.5
Fulcaster	187	5.4	5.2	105	110	+0.2
Fulcaster	184	5.4	5.4	106	107	0.0
Fulcaster	175	5.4	5.5	107	104	—0.1
Fulcaster	166	5.4	5.3	108	108	+0.1
Fulcaster	160	5.4	5.7	109	98	—0.3
Harvest Queen	225	5.3	6.1	110	92	—0.8
Miracle	211	5.3	5.2	111	111	+0.1
Marquis X Kanred	208	5.2	5.9	112	96	—0.7
Turkey	152	5.2	5.2	113	112	0.0
Turkey	142	5.1	4.9	114	116	+0.2
Turkey	119	5.1	4.0	115	129	+1.1
Fulcaster	174	5.0	5.1	116	114	—0.1
Fulcaster	172	5.0	5.0	117	115	0.0
Turkey	143	5.0	4.5	118	119	+0.5
Turkey	131	5.0	4.5	119	120	+0.5
Kanred X Marquis	198	4.9	4.9	120	117	0.0
Fulcaster	176	4.9	4.9	121	118	0.0
Turkey	125	4.8	4.2	122	127	+0.6
Turkey	115	4.8	3.8	123	135	+1.0
Turkey	114	4.8	3.7	124	136	+1.1
Turkey	136	4.7	4.4	125	122	+0.3
Fulcaster	186	4.6	4.4	126	123	+0.2
P1066 Selection	210	4.5	4.0	127	130	+0.5
P1066 X Preston	199	4.5	4.3	128	124	+0.2
Turkey	137	4.5	4.2	129	128	+0.3
Turkey	124	4.5	4.0	130	131	+0.5
Turkey	117	4.5	3.5	131	140	+1.0
Turkey	149	4.4	4.3	132	125	+0.1

TABLE 3.—*Continued.*

Variety	Row No.	Yield Before correction	Yield After correction	Placing Before correction	Placing After correction	Difference, actual—corrected
Turkey	130	4.4	4.3	133	126	+0.1
P1068 Selection	200	4.2	3.9	134	134	+0.3
Turkey	144	4.2	4.0	135	132	+0.2
Kanred	293	4.1	4.0	136	133	+0.1
Fultz	248	4.1	3.7	137	137	+0.4
Turkey	112	4.0	3.1	138	152	+0.9
Turkey	138	3.9	3.6	139	139	+0.3
Marquis X Kanred	204	3.8	3.7	140	138	+0.1
Turkey	150	3.8	3.3	141	149	+0.5
Fulhio	323	3.7	4.5	142	121	—0.8
Kanred	191	3.7	3.5	143	141	+0.2
Turkey	148	3.7	3.5	144	142	+0.2
Turkey	116	3.7	2.9	145	157	+0.8
Malakov	81	3.7	3.4	146	144	+0.3
Malakov	80	3.7	3.4	147	145	+0.3
Malakov	65	3.7	3.0	148	154	+0.7
Sibleys New Golden No. 91	287	3.6	3.4	149	146	+0.2
Malakov	79	3.6	3.4	150	147	+0.2
Malakov	71	3.6	3.3	151	150	+0.3
Turkey	141	3.5	3.5	152	143	0.0
Fulcaster	168	3.3	3.4	153	148	—0.1
Malakov	105	3.3	2.8	154	159	+0.5
Malakov	91	3.2	3.0	155	155	+0.2
Malakov	76	3.2	2.8	156	160	+0.4
Malakov	296	3.1	3.2	157	151	—0.1
Malakov	92	3.1	2.8	158	161	+0.3
Malakov	78	3.1	2.9	159	158	+0.2
Malakov	70	3.1	2.6	160	165	+0.5
Malakov	66	3.1	2.5	161	166	+0.6
Fulcaster	161	3.0	3.0	162	156	0.0
Sibleys New Golden No. 62	284	2.9	2.8	163	162	+0.1
Malakov	100	2.9	2.4	164	168	+0.5
Turkey	281	2.8	2.7	165	164	+0.1
Turkey	257	2.8	2.8	166	163	0.0
Turkey	113	2.8	2.2	167	171	+0.6
Malakov	88	2.8	2.3	168	169	+0.5
Turkey	118	2.7	1.6	169	185	+1.1
Sibleys New Golden	272	2.6	3.1	170	153	—0.5
Malakov	89	2.6	2.3	171	170	+0.3
Malakov	84	2.6	2.5	172	167	+0.1
Malakov	107	2.5	1.9	173	177	+0.6
Malakov	103	2.5	2.0	174	174	+0 5
Malakov	120	2.4	2.1	175	173	+0.3

TABLE 3.—*Concluded.*

Variety	Row No.	Yield Before correction	Yield After correction	Placing Before correction	Placing After correction	Difference, actual—corrected
Malakov	93	2.3	2.2	176	172	+0.1
Cesko	235	2.2	1.4	177	190	+0.8
Turkey	140	2.2	1.8	178	181	+0.4
Malakov	72	2.2	1.9	179	178	+0.3
Malakov	64	2.2	1.9	180	179	+0.3
Malakov	90	2.1	2.0	181	175	+0.1
Malakov	69	2.1	1.8	182	182	+0.3
Malakov	60	2.0	1.9	183	180	+0.1
Malakov	94	1.9	1.7	184	183	+0.2
Malakov	77	1.9	1.7	185	184	+0.2
Malakov	68	1.8	1.5	186	186	+0.3
Malakov	82	1.8	1.5	187	187	+0.3
Malakov	83	1.8	1.5	188	188	+0.3
Minturki	317	1.8	2.0	189	176	—0.2
Turkey	151	1.7	1.5	190	189	+0.2
Malakov	106	1.6	1.4	191	191	+0.2
Postoloptry	234	1.1	1.0	192	192	+0.1
Turkey	108	1.1	0.9	193	194	+0.2
Malakov	104	1.1	0.8	194	196	+0.3
Malakov	102	1.0	0.8	195	195	+0.2
Minhardi	320	0.9	1.0	196	193	+0.1
Makovik	236	0.6	0.5	197	197	+0.1
Psyily	237	0.5	0.4	198	198	+0.1
Dabrovice	233	0.3	0.3	199	199	0.0

There was a very marked shifting in the ranking of varieties after correction. An elimination figure was calculated for the two classes of varieties, those yielding 7.0 bushels per acre or better and those yielding less than 7.0 bushels. The average of the five leading varieties for each class was taken as the starting point and from this point three times the probable error of a difference was subtracted.[5] In the high-yielding class, the elimination figure was 11.1 before correction and 11.0 after correction. There were 18 varieties or strains above the elimination figure before correction and 38 varieties above after correction. The point of elimination is changed very little in the case of the better-yielding varieties, *although over* twice as many varieties appear above this point as appeared above it before correction. The line of elimination in the group of varieties yielding less than 7.0 bushels was raised from 2.0 to 2.9 bushels.

[5]The formula used was P. E. of Dif. = P. E. $\sqrt{2}$.

There were 16 varieties below the line before correction and 41 varieties below after correction. These data bring out the interesting fact that correcting the yields on the basis of check plats and the regression equation tended to raise the yields of the better-yielding varieties and to lower the yields of the mediocre-yielding varieties. Correcting yields was, therefore, effective in eliminating varieties which were low in yield but was not effective in the group which was above the average in yield.

TABLE 4.—*Comparison of probable errors in wheat rod-rows before and after correction on the basis of check plats and the regression equation.*

Class	P. E. before correction %	P. E. after correction %	Reduction by correcting %
All varieties..	13.7	10.5	23.4
Varieties below 7 bushel..	16.3	13.0	20.2
Varieties yielding 7 bushel and above	8.9	5.6	37.1
Check plats	14.6	—	—
Average reduction..	—	—	26.9

The probable errors for each group before the yields were corrected and after correction are given in Table 4. The check plats were planted with the variety Turkey and the average yield of all checks was 2.47 bushels, therefore, the probable error from checks should compare with that obtained from the varieties yielding less than 7 bushels. There was a decided reduction in the probable error in all cases, but it was most marked in the class yielding 7 bushels or better, the reduction being from 8.9 to 5.6, or 37.1%. The average reduction was 26.9%, and on the basis of Richey's formula[6] for reduction in variability, the probable errors should be reduced anywhere from 20.8% to 29.3% based on the correlation between the yields of adjacent or nearby plats.

METHODS OF CALCULATING PROBABLE ERRORS

Several methods of calculating probable errors have been used, and there is some question as to whether it is legitimate to calculate a probable error on the basis of a large number of checks and apply this probable error to a comparison of varieties whose yields were determined on the basis of four plats only. In the rod-row yield trials discussed earlier in this paper, there were 108 check plats which could be placed in 27 groups of four each replicated systematically

[6]RICHEY, F. D. Adjusting yields to their regression on a moving average as a means of correcting for soil heterogeneity. Jour. Agr. Res., 27:79–90. 1924.

the same as the varieties in the test. These 27 groups were considered as 27 varieties and the probable error calculated in three ways. First, the probable error was calculated in the usual manner by using the probable error of a single determination based on the yields of all checks. From this the probable error of the experiment was obtained by dividing the P. E. of a single determination by the factor $\sqrt{4}$, since there were four plats of each variety in the test. Second, the probable error as obtained in the first case was expressed in percentage of the mean for all checks and a separate error calculated for each set of four plats. Third, the probable error was calculated separately for each set of four plats. In other words, this last probable error is an error of the mean calculated from four individuals. The yields of the checks and the probable errors by the three methods are given in Table 5. There is considerable variation in the size of the probable errors calculated by the second and third methods.

TABLE 5.—*Yields of check plats, average of four, and the probable errors as calculated by the three methods explained in the text.*

No.	Yields of checks	Probable error in bushels by Method		
		1	2	3
1	2.43	±0.36	±0.36	±0.41
2	1.88	±0.36	±0.28	±0.33
3	1.63	±0.36	±0.24	±0.24
4	2.15	±0.36	±0.32	±0.31
5	2.93	±0.36	±0.43	±0.49
6	2.40	±0.36	±0.35	±0.40
7	2.93	±0.36	±0.43	±0.36
8	2.75	±0.36	±0.40	±0.34
9	3.83	±0.36	±0.56	±0.51
10	3.20	±0.36	±0.47	±0.18
11	2.63	±0.36	±0.39	±0.40
12	2.98	±0.36	±0.42	±0.43
13	2.28	±0.36	±0.34	±0.27
14	2.68	±0.36	±0.39	±0.45
15	2.33	±0.36	±0.34	±0.30
16	2.50	±0.36	±0.37	±0.32
17	2.88	±0.36	±0.42	±0.38
18	2.35	±0.36	±0.35	±0.28
19	1.83	±0.36	±0.27	±0.23
20	2.78	±0.36	±0.41	±0.53
21	2.75	±0.36	±0.40	±0.26
22	1.93	±0.36	±0.28	±0.23
23	1.88	±0.36	±0.28	±0.20
24	3.10	±0.36	±0.46	±0.42
25	1.60	±0.36	±0.24	±0.28
26	1.55	±0.36	±0.23	±0.21
27	2.45	±0.36	±0.36	±0.38

According to the theory of error, the probable error is a term "used to denote the amount that must be added to or subtracted from the observed value to obtain two limiting figures of which it may be said that there is an even chance that the true value lies within or without these limits."[7] Since the average for all the checks was 2.47 bushels per acre, this is the true value for this set of data. The average for each set of four plats represents an observed value. Table 6 gives a comparison of the observed and calculated for 27 trials on the basis of one, two, three, and four times the probable error.

TABLE 6.—*Comparison of the actual results obtained by three methods of calculating probable errors and the distribution expected on the basis of random sampling.*

Method	Ratio of cases in which true value fell within limits of mean ± P. E. to cases in which it fell without these limits			
	± P. E.	± 2 P. E.	± 3 P. E.	± 4. P. E.
First	13:14	22.5	26:1	27:0
Second	13:14	19:8	24:3	27:0
Third	13:14	19:8	23:4	25:2
Calculated on basis of random sampling	13.5:13 5	22.2:4.8	25.8:1.2	26.8:0.2

On the basis of the actual distribution as compared to the calculated, the first method is the most reliable in this test.

The yields of a test of this nature are comparative. In order to determine whether one variety is better than another, they are compared in the light of the probable error of the experiment or both are compared with a standard variety. Take, for example, checks Nos. 9 and 26, the yields are, respectively, 3.83 and 1.55 bushels per acre. The difference divided by the probable error of a difference is 4.5 for the first method of calculation, 3.7 for the second method, and 4.1 for the third method. It should be kept in mind that these two yields are from the same variety and each is the average of four plats. A similar comparison of No. 9 with No. 25 shows the difference to be 4.4 times the probable error of the difference for the first method, 4.0 for the second method, and 3.8 for the third method. On the basis of this comparison, there seems to be very little difference which method is used in calculating the probable error.

In general, the yields of the hard wheats were low. Consequently, a slight variation in soil might be a large percentage variation. It has been shown earlier in this article that the soft wheats in general showed less variation than the hard wheats. It may be said, how-

[7]BABCOCK, E. B., and CLAUSEN, R. E. Genetics in Relation to Agriculture. New York: McGraw-Hill Book Company. 675 pages. 1918.

ever, that before further efforts are made to reduce the probable error by means of extensive calculation, an effort should be made to increase the accuracy of the actual results by use of more uniform soil. It has been shown that in case of the check plats that two sets of four plats each may differ in yield to the extent of four to five times the probable error of their difference. It has also been shown in Table 6 that the variation in these same check plats is in fairly good agreement with the calculated variation on the basis of random sampling. This indicates that considering three or four times the probable error of a difference as significant may result in the discarding of an occasional variety of value. However, in a test including several hundred varieties, some must be discarded and it is felt that the few errors will not be very serious especially when there are a number of varieties in the test equally as good for other characteristics than yield as those subject to discard. It is apparent, nevertheless, that under conditions of extreme soil variability that differences of three or four times the probable error of a difference may occur as variations due to random sampling.

SUMMARY

1. Correlations were calculated in rod-row trials according to the method devised by Hayes. The correlations varied from 0.611 ± .019 for plats 10 feet apart to 0.707 ± .015 for rows 3 feet apart.

2. Corrected yields of the varieties were calculated by means of the regression equations and the check plats. The ranking of varieties was changed by correction. In the group of wheats yielding 7.0 bushels per acre or better, there was a tendency for yields to be raised by the correction, while in the group yielding less than 7.0 bushels the yields seemed to be depressed.

3. The probable errors were reduced by correcting the yields. The probable errors calculated by the deviation from the mean method were reduced 37.1% for the class of wheats yielding 7.0 bushels or better and 20.2% for varieties yielding less than 7.0 bushels per acre.

4. Probable errors were calculated from the check plats by three different methods. The probable error calculated from all the checks and expressed in bushels agreed the best with that calculated on the basis of variation due to random sampling.

YIELDS OF ADJACENT ROWS OF SORGHUMS IN VARIETY AND SPACING TESTS[1]

K. H. KLAGES[2]

The accuracy and reliability of field tests are ever affected by the methods employed in such experiments. In variety tests of row crops, the degree of competition between rows of adjacent varieties should determine whether or not border rows will be necessary. In the case of row crops spaced the ordinary distance of 3½ feet, a large area of the test plat will be occupied by such border rows. In three-row plats this will amount to 66⅔%, in four-row plats to 50%, in five-row plats to 40% of the total area, etc. Frequently, the area available for variety tests is limited. In such cases much may be gained if it is found that the elimination of the border rows does not interfere with the accuracy of the test. Even where the area available for such tests need not be considered, the employment of smaller plats made possible by the absence of border rows allows for a greater number of replications. The fact that a variety test may be conducted on a smaller area serves in many cases to keep down the disturbing influence of soil heterogeneity in so far as a small uniform plat not extending into a variety of soil types may be selected.

The purpose of this investigation was to find to what degree the yields of rows of adjacent varieties were influenced by competition and to find whether or not border rows are essential to the accuracy of sorghum variety tests under conditions that prevail at the Oklahoma Agricultural Experiment Station.

PLAN OF EXPERIMENT

The forage yields of varieties of grain and sweet sorghums as well as those of a rate of planting test with Blackhull kafir were used in this investigation. The work extended over a period of two years, 1926 and 1927. The yields of 1,525 individual rows were used. They were divided as follows: 300 rows of grain sorghums, 300 rows of sweet sorghums, and 75 rows of kafir from the rate of planting test of 1926, and 820 rows of grain and sweet sorghums and 30 of kafir in the rate of planting test of 1927.

Yields reported, except where stated otherwise, refer to green weights. The weights were taken immediately after cutting. All yields except where expressed on a percentage basis are stated in tons per acre.

[1]Contribution from the Department of Field Crops and Soils, Oklahoma Agricultural and Mechanical College, Stillwater, Okla. Published with the approval of the Director of the Experiment Station. Received for publication March 19, 1928.

[2]Assistant Professor of Agronomy, in charge of Forage Crops Investigations.

In 1926, the grain and sweet sorghums were grown on separate series. The plats, however, were laid out in like manner and the same system of numbering used. All rows of the 1926 tests, grain sorghums sweet sorghums, and rate of planting tests, extended from north to south. In 1927, all rows extended from east to west. In 1927 the grain and sweet sorghums were grown on the same series.

Five-row plats were used in all instances. The distance between the rows was 3½ feet. In 1926, the rows of plats of the variety test were 100 feet in length, in 1927 they were only 44 feet long. Rows will be referred to by their respective numbers, as 1, 2, 3, 4, and 5. Rows 1 and 5 represent the two outside and 2, 3, and 4 the three inside rows of the plat.

All varieties were planted throughout four dates, namely, April 15, May 1, May 15, and June 1. These dates will hereafter be referred to as the first, second, third, and fourth dates of planting, respectively.

Figs. 1 and 2 show the arrangement of the plats in the variety tests of 1926 and 1927. Attention is called to the system of numbering employed. The first cipher indicates the date of planting as 1, 2, 3, and 4, while the last two ciphers serve to designate the variety and its relative position in the test plat.

	Bo	rder	
115	215	315	415
114	214	314	414
113	213	313	413
112	212	312	412
111	211	311	411
110	210	310	410
109	209	309	409
108	208	308	408
107	207	307	407
106	206	306	406
105	205	305	405
104	204	304	404
103	203	303	403
102	202	302	402
101	201	301	401
	Bo	rder	

N ←

FIG. 1.—Showing arrangement of plats of grain sorghums, 1926.

Six check plats of Black hull kafir were used in the 1927 variety test for each date of planting. These check plats were arranged diagonally across the series. They are, for that reason, readily detected from their respective numbers. In the check plats, the last two ciphers of the plat number are alike as 111, 122, 466, etc. Plat 76 for the four dates of planting was in corn for the sake of comparing corn with sorghum yields. It is not considered in this investigation.

The soil of the experimental plats was a moderately fertile Kirkland silt loam.

EXPERIMENTAL RESULTS

YIELDS OF INDIVIDUAL ROWS ON A PERCENTAGE BASIS

In the event of active competition between adjacent rows of different varieties, the yields of the outside rows of such plats may be expected to be less constant than those of the interior rows protected from the disturbing influence of intervarietal competition. When, on the other hand, the yields of the outside rows do not differ significantly from those of the protected interior rows, the deduction may be made that competition does not constitute a disturbing factor under the prevailing conditions. In the case of active competition, the degree of variability of the outside rows may be expected to be greater than that of the interior rows.

TABLE 1.—*Comparative yields of individual rows expressed on a percentage basis, grain sorghum varieties, 1926.*

Variety	Plat No.	Row 1	Row 2	Row 3	Row 4	Row 5
Blackhull kafir	1	107.6	94.5	93.1	103.0	101.9
Reed's kafir	2	100.1	93.3	100.6	101.5	104.7
Sunrise kafir	3	94.1	95.1	95.8	107.3	107.7
Dawn kafir	4	108.7	99.3	96.6	100.0	95.3
Early kafir	5	102 0	100.1	100.2	97.6	100.0
Bishops kafir	6	96.3	95.9	97.8	101.4	108.6
Pink kafir	7	93.7	97.4	104.7	100.3	103.8
Red kafir	8	105.8	109.9	91.3	99.1	94.4
Pearl kafir	9	101.8	94.4	102.8	102.6	98.3
Schrock kafir[a]	10	113.0	98.4	96.9	95.6	96.1
Darso	11	97.4	98.6	98.1	103.0	103.1
Spur feterita	12	107.1	98.3	92.0	100.0	105.1
Dwarf feterita	13	82.2	101.4	103.5	105.3	107.6
Hegari	14	110.2	98.7	98.0	92.2	101.0
White kaoliang	15	96.0	93.6	84.7	104.3	121.3
Mean		100.9	97.9	96.9	101.0	103.4
		±1.1	±0.7	±0.8	±0.9	±0.9

[a]Average of first, second, and fourth dates of planting only.

Table 1 gives the comparative yields of individual rows of the 15 varieties of grain sorghums in the variety test of 1926. These yields are expressed on the basis of percentage of the average of the separate varieties. For the sake of conserving space, only the averages of the four dates of planting are given. This is allowable in so far as the arrangement of the plats for the several dates of planting, both for 1926 and 1927, is identical as may be seen from Figs. 1 and 2. Table 2 gives the same information for the 14 varieties of sweet sorghums and the Blackhull kafir check in the variety test of 1926. The same arrangement and system of numbering as given for the grain sorghums in Fig. 1 was used with the sorgos. Table 3 gives the yields of indi-

vidual rows of 17 varieties of grain sorghums and 19 varieties of sweet sorghums, together with those of the check plats. The arrangement of these plats is shown in Fig. 2.

TABLE 2.—*Comparative yields of individual rows expressed on a percentage basis, sweet sorghum varieties, 1926.*

Variety	Plat No.	Row 1	Row 2	Row 3	Row 4	Row 5
Sumac	1	99.7	106.2	93.0	104.0	96.4
Orange	2	102.8	102.5	100.1	93.4	101.3
Kansas Orange[a]	3	85.4	114.4	102.9	96.9	100.4
Honey	4	107.5	92.7	98.8	97.0	104.2
Red Amber	5	98.5	104.6	94.7	112.8	89.4
Black Amber	6	100.5	100.5	101.6	96.4	101.0
African millet	7	91.6	99.8	102.0	104.1	101.3
Blackhull kafir (Check)	8	90.5	96.0	113.0	100.1	100.4
Dwarf Ashburn	9	100.0	96.2	99.1	97.4	108.3
Texas Seeded Ribbon	10	84.4	108.4	108.1	98.6	100.6
Gooseneck	11	114.5	102.3	109.5	94.9	78.8
Coleman	12	105.2	96.7	97.2	100.8	100.1
McClain	13	103.4	91.3	109.9	97.2	98.2
Folger	14	98.4	94.7	98.4	100.4	108.1
Freed	15	89.9	102.0	102.4	100.1	105.7
Mean		98.5 ±1.2	100.3 ±0.9	102.0 ±0.9	99.7 ±0.8	99.5 ±1.1

[a]Average of first, second, and fourth dates of planting only.

The calculations of the means and their respective probable errors, $P. E._m = \frac{0.6745}{\sqrt{n}}$, are based on all variables concerned, all yields of the separate dates of planting for each of the varieties included were taken into account. The values for "n" were 59, 59, and 156 for the data presented in Tables 1, 2, and 3, respectively.

The means for the five individual rows, Tables 1, 2, and 3, do not differ significantly from the average yields of all five rows, 100%. There are, however, instances where the yields of separate rows differ widely from 100% as in the case of Dwarf feterita. The reason for the abnormally high yield of row 1 is readily found upon a consideration of its behavior at its first date of planting where the yields of rows 1 to 5 were 232.9, 56.8, 11.4, 73.9, and 125.0%, respectively. This abnormal behavior can be attributed altogether to differences in densities of stands of the respective rows rather than to competition. The number of plants for rows 1, 2, 3, 4, and 5 expressed on a percentage basis were 218.8, 41.7, 20.8, 104.2, and 114.6, respectively. The comparatively high yields of the first two rows of Black Amber (Table 3) are accounted for by the behavior of this

TABLE 3.—*Comparative yields of individual rows expressed on a percentage basis, grain and sweet sorghum varieties, 1927.*

Variety	Plat No.	Row 1	Row 2	Row 3	Row 4	Row 5
Blackhull kafir	11	82.7	111.1	92.4	103.5	110.3
Early kafir	21	111.2	94.4	97.3	99.0	98.1
Spur feterita	31	87.8	89.3	101.8	109.2	112.0
Hegari[a]	41	96.6	94.2	114.4	94.6	100.1
Clubhead	51	98.3	100.5	102.2	103.0	96.0
Honey	61	111.3	91.5	113.7	96.2	87.3
Coleman	71	104.3	110.1	98.5	99.0	88.2
Reed's kafir	12	85.8	103.9	113.9	104.4	92.0
Blackhull kafir	22	123.3	86.3	98.9	95.1	96.5
Dwarf feterita	32	142.0	85.8	76.4	87.4	108.4
African millet[b]	42	107.5	96.0	98.6	98.3	99.7
Gooseneck[c]	52	79.5	95.2	107.0	118.7	99.5
Early Rose	62	94.0	90.0	108.5	112.3	95.2
Collier	72	118.2	109.0	96.2	94.6	81.9
Red kafir	13	83.7	108.3	100.9	106.2	101.0
Streigh Neck maize[c]	23	124.4	97.6	88.4	112.7	77.0
Blackhull kafir	33	97.7	118.3	90.2	101.6	92.3
White African	43	101.5	94.4	99.0	103.5	101.6
Texas Seeded Ribbon[c]	53	112.8	79.8	114.7	91.4	101.3
Sugar Drip	63	106.9	101.7	101.9	93.3	96.2
Folger	73	100.3	111.3	97.9	101.4	89.2
Desert maize[c]	14	89.8	79.7	101.3	126.7	102.4
Bishop kafir	24	112.1	105.9	94.2	100.9	86.9
Common feterita	34	85.6	104.2	105.4	99.5	105.1
Blackhull kafir	44	102.7	92.0	114.0	95.9	95.5
Dwarf Ashburn	54	107.4	101.0	100.9	94.3	96.3
McClain	64	99.9	101.3	112.4	102.6	83.8
Red Amber	74	117.6	126.0	104.3	72.0	80.1
Pink kafir	15	96.4	104.6	96.2	97.9	104.9
Pearl kafir	25	110.5	99.0	86.1	102.3	102.3
Darso	35	105.4	97.8	89.9	102.4	104.4
Kansas Orange[c]	45	92.4	98.7	110.3	93.1	105.6
Blackhull kafir	55	105.9	95.6	97.9	103.6	94.1
Early Sumac[c]	65	99.9	91.6	110.0	106.2	92.3
Black Amber	75	127.3	120.5	97.5	75.2	79.6
Sunrise kafir	16	76.9	99.6	105.5	110.5	107.5
Dawn kafir	26	97.9	92.9	101.7	110.6	96.8
Schrock kafir	36	106.7	103.9	95.0	101.9	92.6
Orange	46	93.6	103.2	99.4	101.2	102.6
Sumac	56	99.9	94.8	104.9	98.7	101.7
Blackhull kafir	66	99.4	95.0	106.9	108.1	90.6
Mean	—	102.5 ±1.4	99.8 ±1.0	101.0 ±0.9	100.5 ±1.1	96.1 ±1.4

[a]Average of first three dates of planting only.

[b]Average of first, second, and fourth dates of planting only.

[c]Fourth planting destroyed by chinch bugs.

variety at the fourth planting where the yields of the five rows were 196.7, 196.7, 82.0, 16.4, and 8.2%, respectively. The same situation relative to yields of individual rows for the fourth planting is found in the case of Red Amber, Coleman, Collier, and Folger, or on plats 470 to 475, inclusive. As may be seen from Fig. 2 these plats were located across the north end of the series. They were in the direct path of a chinch bug invasion, which accounts for the gradations in relative yields from row 5 to row 1.

Table 4 gives the average relative yields of the separate rows of the variety tests of 1926 and 1927, together with the averages for the different dates of planting.

		Bor	der		
116	115	114	113	112	111
126	125	124	123	122	121
136	135	134	133	132	131
146	145	144	143	142	141
156	155	154	153	152	151
166	165	164	163	162	161
176	175	174	173	172	171
216	215	214	213	212	211
226	225	224	223	222	221
236	235	234	233	232	231
246	245	244	243	242	241
256	255	254	253	252	251
266	265	264	263	262	261
276	275	274	273	272	271
316	315	314	313	312	311
326	325	324	323	322	321
336	335	334	333	332	331
346	345	344	343	342	341
356	355	354	353	352	351
366	365	364	363	362	361
376	375	374	373	372	371
416	415	414	413	412	411
426	425	424	423	422	421
436	435	434	433	432	431
446	445	444	443	442	441
456	455	454	453	452	451
466	465	464	463	462	461
476	475	474	473	472	471
		Bor	der		

FIG. 2.—Showing arrangement of sorghum tests plats, 1927.

When the differences in the yields of the separate rows are considered in the light of their probable errors, they are not significant.

TABLE 4.—*Comparative yields of individual rows expressed on a percentage basis, averages of all varieties at different dates of planting.*

Date of planting	Row 1	Row 2	Row 3	Row 4	Row 5
			Grain Sorghums, 1926		
1	102.6±1.7	99.3±1.8	97.7±2.0	96.4±1.6	104.0±1.9
2	100.8±1.8	98.9±1.2	96.8±1.8	103.1±1.2	100.4±1.4
3	99.0±1.9	98.0±1.3	92.3±1.0	103.5±1.4	107.2±1.7
4	101.1±2.8	95.4±1.3	100.5±1.3	101.1±2.4	102.0±1.5
Average	100.9±1.1	97.9±0.7	96.9±0.8	101.0±0.9	103.4±0.9
			Sweet Sorghums, 1926		
1	98.3±1.8	101.3±1.5	100.8±1.3	98.2±1.4	101.3±1.7
2	102.9±2.0	103.1±1.8	99.4±1.9	95.3±1.7	99.3±1.5
3	99.7±2.4	96.0±1.9	104.2±1.9	100.4±1.4	99.5±1.1
4	92.9±3.0	100.6±2.0	103.9±2.1	105.0±1.5	97.8±3.1
Average	98.5±1.2	100.3±0.9	102.0±0.9	99.7±0.8	99.5±1.1
			Grain and Sweet Sorghums, 1927		
1	101.4±2.7	98.4±1.3	103.2±2.2	100.5±1.2	96.6±3.0
2	102.7±1.7	94.5±1.2	101.8±1.4	101.9±1.2	99.1±1.4
3	100.6±2.5	98.7±1.9	94.7±1.8	106.5±2.4	99.3±2.1
4	105.7±3.9	109.7±3.3	104.7±1.6	91.5±3.0	89.0±3.8
Average	102.5±1.4	99.8±1.0	101.0±0.9	100.5±1.1	96.1±1.0
Average for 1926 and 1927	100.6	99.3	100.0	100.4	99.7

TABLE 5.—*Comparative yields in tons per acre of individual rows and combination of rows, grain sorghum varieties, 1926.*

Variety	Plat No.	Row 1	Row 5	Row 3	Rows 1 and 5	Rows 2, 3, and 4	Rows 1, 2, 3, 4, and 5
Blackhull kafir	1	4.70	4.45	4.03	4.57	4.23	4.37
Reed's kafir	2	3.28	3.42	3.30	3.36	3.22	3.27
Sunrise kafir	3	3.70	4.22	3.77	3.96	3.90	3.93
Dawn kafir	4	4.01	3.51	3.56	3.76	3.63	3.69
Early kafir	5	4.73	4.65	4.65	4.69	4.60	4.64
Bishop kafir	6	3.62	4.06	3.67	3.85	3.70	3.76
Pink kafir	7	3.04	3.38	3.41	3.20	3.28	3.25
Red kafir	8	3.89	3.48	3.37	3.68	3.69	3.69
Pearl kafir	9	4.84	4.65	4.88	4.75	4.74	4.74
Schrock kafir[a]	10	5.00	4.21	4.26	4.61	4.21	4.37
Darso	11	3.38	3.56	3.34	3.47	3.40	3.43
Spur feterita	12	3.64	3.66	3.19	3.65	3.45	3.53
Dwarf feterita	13	2.22	2.83	2.80	2.51	2.87	2.66
Hegari	14	4.65	4.29	4.12	4.49	4.08	4.24
White kaoliang	15	3.28	4.36	2.89	3.82	3.27	3.49
Mean		3.84 ±.08	3.91 ±.07	3.67 ±.07	3.88 ±.07	3.74 ±.07	3.80 ±.07

[a]Average of first, second, and fourth dates of planting only.

In the grain sorghums of 1926 there is a tendency for high yields in the two outside rows. In the sweet sorghums, on the other hand, the middle row shows a tendency to rise above 100%. In the tests of 1927 row 1 as well as row 3 exhibited a trend to surpass the average. The low yields of row 5 have already been accounted for.

YIELDS OF INDIVIDUAL ROWS AND COMBINATIONS OF ROWS WITH SPECIAL REFERENCE TO COMPARATIVE YIELDS OF INSIDE AND OUTSIDE ROWS

As has already been mentioned, the yields of outside rows of plats may be expected to correspond well with those of inside rows in the absence of intervarietal competition. With that in view, the yields of the two outside rows, 1 and 5, of an inside row, 2, 3, or 4, and the average of all five rows were compared. These data are given in Tables 5, 6, and 7 for the grain sorghums of 1926, for the sweet sorghums of that year, and for both the grain and the sweet sorghums of 1927. The figures represent averages for the four dates of planting.

TABLE 6.- *Comparative yields, in tons per acre, on individual rows and combination of rows, sweet sorghum varieties, 1926.*

Variety	Plat No.	Row 1	Row 5	Row 3	Rows 1 and 5	Rows 2, 3, and 4	Rows 1, 2, 3, 4, and 5
Sumac	1	7.92	7.66	7.36	7.80	7.89	7.86
Orange	2	7.58	7.48	7.37	7.54	7.26	7.37
Kansas Orange[a]	3	5.25	5.66	5.83	5.46	6.06	5.82
Honey	4	4.96	4.90	4.58	4.93	4.45	4.64
Red Amber	5	4.39	4.25	4.26	4.32	4.69	4.54
Black Amber	6	3.87	3.98	4.08	3.93	3.94	3.94
African millet	7	6.33	6.77	6.67	6.55	6.67	6.61
Blackhull kafir (check)	8	3.73	3.91	4.57	3.83	4.10	3.99
Dwarf Ashburn	9	5.71	6.03	5.59	5.87	5.50	5.65
Texas Seeded Ribbon	10	4.12	4.70	5.20	4.42	4.98	4.75
Gooseneck	11	7.02	4.77	6.07	5.89	5.96	5.93
Coleman	12	5.24	5.00	4.84	5.12	4.91	4.99
McClain	13	6.64	6.35	7.00	6.50	6.34	6.40
Folger	14	4.12	4.56	4.20	4.34	4.18	4.25
Freed	15	3.10	3.61	3.47	3.36	3.46	3.42
Mean		5.33	5.30	5.40	5.32	5.34	5.33
		±.19	±.17	±.17	±.14	±.16	±.17

[a]Average of first, second, and fourth dates of planting only.

It will be noticed from Tables 5, 6, and 7 that the yields of the three inside rows are in all cases close to those of all five rows. The yields of the outside rows correspond in practically all cases closely to those of inside rows. A somewhat greater variation is to be expected in their yields since they represent the average of two rows only as compared to three for the inside rows. An even greater variation in the yields of single rows is excusable in the yields of the

Table 7.—*Comparative yields, in tons per acre, of individual rows and combination of rows of sorghum varieties, 1927.*

Variety	Plat No.	Row 1	Row 5	Row 3	Rows 1 and 5	Rows 2, 3, and 4	Rows 1, 2, 3, 4, and 5
Blackhull kafir	11	4.15	5.45	4.57	4.79	5.06	4.95
Early kafir	21	6.23	5.41	5.42	5.82	5.45	5.55
Spur feterita	31	4.85	6.15	5.55	5.50	5.53	5.53
Hegari[a]	41	4.11	4.86	5.00	4.50	4.32	4.40
Clubhead	51	5.55	5.62	5.87	5.59	5.92	5.79
Honey	61	8.03	6.22	8.10	7.18	7.28	7.24
Coleman	71	7.78	7.68	7.47	7.73	7.82	7.79
Reed's kafir	12	3.96	4.32	4.99	4.14	4.83	4.55
Blackhull kafir	22	6.86	5.45	5.59	6.16	5.25	5.53
Dwarf feterita	32	4.92	3.93	3.11	4.42	3.22	3.70
African millet[b]	42	9.90	8.87	8.96	9.39	8.94	9.12
Gooseneck[c]	52	6.18	7.45	7.59	6.73	7.76	7.39
Early Rose	62	6.05	5.98	6.79	6.01	6.67	6.40
Collier	72	5.70	4.74	5.13	5.19	5.32	5.28
Red kafir	13	4.92	5.63	5.59	5.27	5.84	5.61
Streight Neck maize[c]	23	5.33	3.30	3.77	4.31	4.28	4.29
Blackhull kafir	33	5.59	5.38	5.20	5.48	5.87	5.72
White African	43	8.92	9.16	8.88	9.04	8.92	8.97
Texas Seeded Ribbon[c]	53	4.58	3.96	4.95	4.27	3.99	4.11
Sugar Drip	63	7.18	6.58	6.72	6.89	6.73	6.79
Folger	73	6.05	7.22	6.26	6.63	6.63	6.63
Desert maize[c]	14	2.26	1.98	2.60	2.12	2.33	2.24
Bishop kafir	24	6.79	5.27	5.64	6.03	6.10	6.07
Common feterita	34	5.84	7.11	6.90	6.48	6.82	6.68
Blackhull kafir	44	5.63	5.34	6.26	5.48	5.58	5.55
Dwarf Ashburn	54	7.71	6.93	7.29	7.32	7.22	7.26
McClain	64	10.08	8.57	10.89	9.32	10.16	9.82
Red Amber	74	7.40	7.50	7.11	7.45	7.13	7.23
Pink kafir	15	4.71	4.85	4.67	4.77	4.81	4.80
Pearl kafir	25	6.97	6.48	5.63	6.72	6.04	6.37
Darso	35	7.01	6.87	5.98	6.93	6.47	6.66
Kansas Orange[c]	45	10.99	12.55	13.16	11.77	12.44	11.97
Blackhull kafir	55	5.94	5.24	5.63	5.59	5.60	5.60
Early Sumac[c]	65	8.54	7.74	9.20	8.13	8.63	8.43
Black Amber	75	6.44	6.12	6.02	6.28	5.85	5.99
Sunrise kafir	16	4.17	5.31	5.38	4.74	5.31	5.08
Dawn kafir	26	5.27	5.09	5.13	5.18	5.41	5.32
Schrock kafir	36	6.72	6.01	6.16	6.37	6.52	6.46
Orange	46	8.92	9.98	9.62	9.44	9.84	9.69
Sumac	56	11.29	11.39	11.85	11.34	11.11	11.20
Blackhull kafir	66	5.84	5.34	6.33	5.59	6.11	5.90
Mean		6.47 ±.14	6.32 ±.15	6.50 ±.15	6.39 ±.14	6.46 ±.14	6.43 ±.14

[a]Average of first three dates of planting only.
[b]Average of first, second, and fourth dates of planting only.
[c]Fourth planting destroyed by chinch bugs.

individual rows for the reason that determinations are based on only half as many rows.

Table 8 gives the average relative yields of individual rows and combinations of rows of the variety tests of 1926 and 1927, together with the averages for the four dates of planting.

TABLE 8.—*Comparative yields of individual rows and combination of rows, averages of all varieties at different dates of planting.*

Date of planting	Row 1	Row 5	Row 3	Rows 1 and 5	Rows 2, 3, and 4	Rows 1, 2, 3, 4, and 5
			Grain Sorghums, 1926			
1	4.25±.17	4.27±.15	4.01±.15	4.26±.15	4.05±.11	4.12±.13
2	4.20±.16	4.14±.08	4.00±.12	4.17±.12	4.11±.09	4.13±.10
3	3.68±.17	4.00±.14	3.43±.09	3.84±.12	3.65±.10	3.72±.11
4	3.23±.15	3.23±.15	3.24±.15	3.24±.12	3.16±.12	3.19±.12
Average	3.84±.08	3.91±.07	3.67±.07	3.88±.07	3.74±.07	3.79±.07
			Sweet Sorghums, 1926			
1	6.58±.35	6.61±.23	6.66±.28	6.60±.28	6.63±.29	6.62±.28
2	6.37±.32	6.12±.27	6.13±.29	6.25±.29	6.15±.29	6.19±.28
3	5.08±.34	5.03±.33	5.17±.28	5.06±.23	4.98±.26	5.01±.28
4	3.29±.20	3.43±.18	3.61±.17	3.36±.18	3.60±.17	3.50±.17
Average	5.33±.19	5.30±.17	5.40±.17	5.32±.14	5.34±.16	5.33±.17
			Grain and Sweet Sorghums, 1927			
1	6.75±.26	6.51±.24	7.01±.29	6.62±.24	6.81±.25	6.73±.24
2	7.17±.23	7.21±.30	7.24±.28	7.18±.25	7.18±.28	7.17±.27
3	7.25±.29	7.03±.30	6.87±.29	7.14±.28	7.09±.26	7.12±.26
4	4.40±.22	4.17±.23	4.54±.20	4.29±.20	4.41±.20	4.35±.20
Average	6.47±.14	6.32±.15	6.50±.15	6.39±.14	6.46±.14	6.43±.14
Average for 1926 and 1927	5.21	5.18	5.19	5.20	5.18	5.18

Neither the yields of single rows nor those of combinations of rows show significant differences. This leads to the conclusion that single-row plats replicated frequently enough will give as reliable results as do plats with a larger number of rows replicated less frequently. More evidence to that effect is found in Table 9 showing the degree of correlation between the yields of the two outside rows and that of the three protected inside rows. The degree of correlation between row 3 and the three inside rows may be expected to be high due to the fact that it in itself constitutes a third of one of the variables used in the calculation. The values of "r" in the correlations of the yields of the outside rows to those of the inside rows are in all instances significant and uniformly high. Special attention is called to the fact that the value of "r" in no case differs significantly for the same set of outside rows when correlated with the yields of the respective inside rows of the plats. This shows that the two respective

outside rows of the plats were influenced either in like manner or not at all by the rows of adjacent plats.

TABLE 9.—*Correlations of yields of individual outside and inside rows and average yields of all inside rows.*

Date of planting	Value of "r"-yield of row 1 and average of rows 2, 3, and 4	Value of "r"-yield of row 5 and average of rows 2, 3, and 4	Value of "r"-yield of row 3 and average of rows 2, 3, and 4
		Grain Sorghums, 1926	
1	0.83±.05	0.74±.08	0.93±.02
2	0.96±.01	0.70±.09	0.90±.03
3	0.55±.13	0.78±.07	0.98±.01
4	0.76±.07	0.66±.10	0.96±.01
Average	0.78	0.72	0.94
		Sweet Sorghums, 1926	
1	0.91±.03	0.84±.05	0.96±.01
2	0.85±.05	0.96±.01	0.95±.02
3	0.95±.02	0.95±.02	0.91±0.3
4	0.83±.05	0.79±.07	0.94±.02
Average	0.89	0.89	.94
		Grain and Sweet Sorghums, 1927	
1	0.82±.03	0.93±.01	0.96±.01
2	0.93±.01	0.96±.01	0.95±.01
3	0.88±.02	0.87±.02	0.95±.01
4	0.76±.05	0.86±.03	0.97±.01
Average	0.85	0.91	0.96

DEGREE OF VARIABILITY OF INDIVIDUAL ROWS

A given array of data is, whenever possible, best interpreted in the light of its degree of variability. Table 10 gives the standard devi-

TABLE 10.—*Comparative variability of individual rows at different dates of planting expressed by their respective standard deviations.*

Date of planting	Row 1	Row 2	Row 3	Row 4	Row 5	Average of all rows
			Grain Sorghums, 1926			
1	9.51±1.17	10.30±1.27	11.42±1.41	8.77±1.08	11.30±1.39	10.26
2	10.49±1.29	6.81± .84	9.76±1.20	6.97± .86	8.02± .99	8.41
3	10.80±1.39	6.99±. 89	5.49± .70	7.84±1.00	10.13±1.29	8.25
4	16.04±2.02	7.00± .86	7.50± .92	14.18±1.75	8.64±1.06	10.67
Average	11.71	7.78	8.54	9.44	9.55	
			Sweet Sorghums, 1926			
1	10.16±1.25	8.35±1.03	7.33± .90	7.81± .96	9.55±1.18	8.64
2	11.22±1.38	10.23±1.26	10.78±1.33	9.85±1.21	8.48±1.04	10.11
3	13.26±1.69	10.73±1.37	10.71±1.37	7.68± .98	11.08±1.41	10.69
4	17.41±2.14	11.58±1.43	11.93±1.47	8.70±1.07	18.05±2.22	13.53
Average	13.01	10.22	10.19	8.51	11.79	
			Grain and Sweet Sorghums, 1927			
1	25.45±1.90	12.40± .92	20.66±1.54	11.60±1.54	28.42±2.12	19.71
2	16.44±1.22	11.59± .89	13.62±1.01	11.58± .86	12.97± .97	13.24
3	23.66±1.78	17.86±1.35	17.22±1.30	22.76±1.72	19.88±1.50	20.28
4	33.31±2.72	28.32±2.32	14.19±1.16	26.23±2.15	32.52±2.66	26.91
Average	24.72	17.54	16.42	18.04	23.75	

ations for the yield of individual rows with such yields expressed on a percentage basis. Table 11 gives the same data for individual rows and combinations of rows. The calculations reported in Table 11 are based on actual yields expressed in tons per acre.

Table 12 shows the standard deviations of individual rows of the three groups of variety tests irrespective of the dates of planting. The values of n, $\sigma = \frac{\sqrt{\Sigma X^2 - (\Sigma X)\ M_x}}{\sqrt{n}}$, were 59, 59, and 156 for the grain sorghums of 1926, for the sorgos of that year, and for the grain and sweet sorghums of 1927, respectively.[4] The values check well with the averages given in Table 10. Table 12, of course, may be criticised from the standpoint of utilization of two variables, *viz.*, yields and different dates of planting. The fact that the same arrangement of plats was adhered to at the various dates of planting should serve to modify such criticism.

TABLE 11.—*Comparative variability of individual rows and combinations of rows at different dates of planting expressed by their respective standard deviations.*

Date of planting	Row 1	Row 5	Row 3	Rows 1 and 5	Rows 2, 3, and 4	Rows 1, 2, 3, 4 and 5
			Grain Sorghums, 1926			
1	0.98±.12	0.84±.10	0.81±.10	0.84±.10	0.65±.08	0.72±.09
2	0.89±.11	0.51±.06	0.70±.09	0.66±.08	0.53±.07	0.58±.07
3	0.96±.13	0.79±.10	0.50±.06	0.67±.09	0.59±.08	0.62±.08
4	0.85±.10	0.88±.11	0.85±.09	0.71±.09	0.70±.09	0.68±.08
Average	0.92	0.76	0.72	0.72	0.62	0.65
			Sweet Sorghums, 1926			
1	2.03±.25	1.34±.17	1.62±.20	1.59±.20	1.64±.20	1.59±.20
2	1.85±.23	1.57±.19	1.64±.20	1.64±.20	1.67±.20	1.62±.20
3	1.91±.24	1.81±.23	1.58±.20	1.80±.23	1.43±.18	1.57±.20
4	1.15±.14	1.07±.13	1.00±.12	1.03±.13	1.00±.12	0.98±.12
Average	1.74	1.45	1.46	1.52	1.44	1.44
			Grain and Sweet Sorghums, 1927			
1	2.50±.19	2.30±.17	2.74±.20	2.31±.17	2.38±.18	2.30±.17
2	2.19±.16	2.81±.21	2.65±.20	2.42±.18	2.67±.20	2.52±.19
3	2.72±.21	2.83±.21	2.74±.21	2.60±.20	2.46±.19	2.47±.19
4	1.93±.16	2.03±.17	1.77±.15	1.78±.15	1.73±.14	1.71±.14
Average	2.34	2.49	2.48	2.28	2.31	2.25

As in the tabulations of the averages of the yields of individual rows (Table 4), or of the yields of combinations of rows (Table 8), there are in Tables 10, 11, and 12 no consistent differences in the respective standard deviations of the yields of these rows. The out-

[4]WALLACE, H. A., and SNEDECOR, GEO. W. Correlation and machine calculation. Iowa State College of Agriculture and Mechanic Arts Official Pub., 23: No. 35. 1925.

TABLE 12.— *Comparative variability of individual rows expressed by their respective standard deviations, three groups of variety tests, 1926 and 1927, yields at all dates of planting assembled.*

Group	Row 1	Row 2	Row 3	Row 4	Row 5
Grain sorghums, 1926	12.90±.77	8.06±.51	9.35±.60	10.18±.65	9.84±.63
Sweet sorghums, 1926	13.90±.89	10.68±.68	10.71±.68	9.34±.60	12.35±.79
Grain and sweet sorghums, 1927	25.05±.96	17.97±.69	16.91±.65	20.38±.78	25.18±.96
Average	17.28	12 24	12.32	13.30	15.79

side rows of the plats exhibit a greater tendency to vary than do the interior rows. The differences are not consistent, however, and in most cases they are not significant. The standard deviations for the yields of rows 1 and 5 (Table 11), are in the greater number of cases not significantly different from those of rows 1, 2, and 3.

The fourth date of planting shows in all cases the greatest degree of variability. Since in the data presented in Table 10, the calculations are based on a percentage yield, and since there are but minor differences between the respective means, the standard deviations for the different dates of planting may be used for direct comparison. A relatively high variability is found in the first planting of grain sorghums in 1926 and in the case of the test of 1927. Relatively higher variations in yields may be expected when varieties are planted at a time removed from their respective optimum dates, such as extremely early or late dates of planting. The exceptionally high values for the last date of planting of the 1927 test are accounted for in part by differences in the abilities of varieties included in the test to resist or to evade chinch bug damage.

YIELDS OF INDIVIDUAL ROWS IN SPACING TESTS

The data for the behavior of individual rows in the spacing tests were obtained in the same manner as those for the variety tests. The rows were 3½ feet apart. The spacings in the rows used in the various five-row plats were 6, 12, 18, 24 and 30 inches. In 1927 an unthinned plat in which the plants were spaced at an average interval of 4 inches in the rows was included. The variety used in these tests was Blackhull kafir.

The plats were arranged in order from the dense to the distant spacing, except that in 1927 the unthinned plat was adjacent to the plat with the plants spaced at intervals of 30 inches. In 1926 all plats were replicated three times. As a result row 5 of the 30-inch spacing plat was adjacent in two cases to row 1 of the 6-inch spacing plat. The length of the rows in 1926 was 120 feet. In 1927 only one series of plats 275 feet in length was used.

Table 13 shows the yields on a percentage basis of individual rows in the spacing tests of 1926 and 1927. The results are shown graphically in Fig. 3.

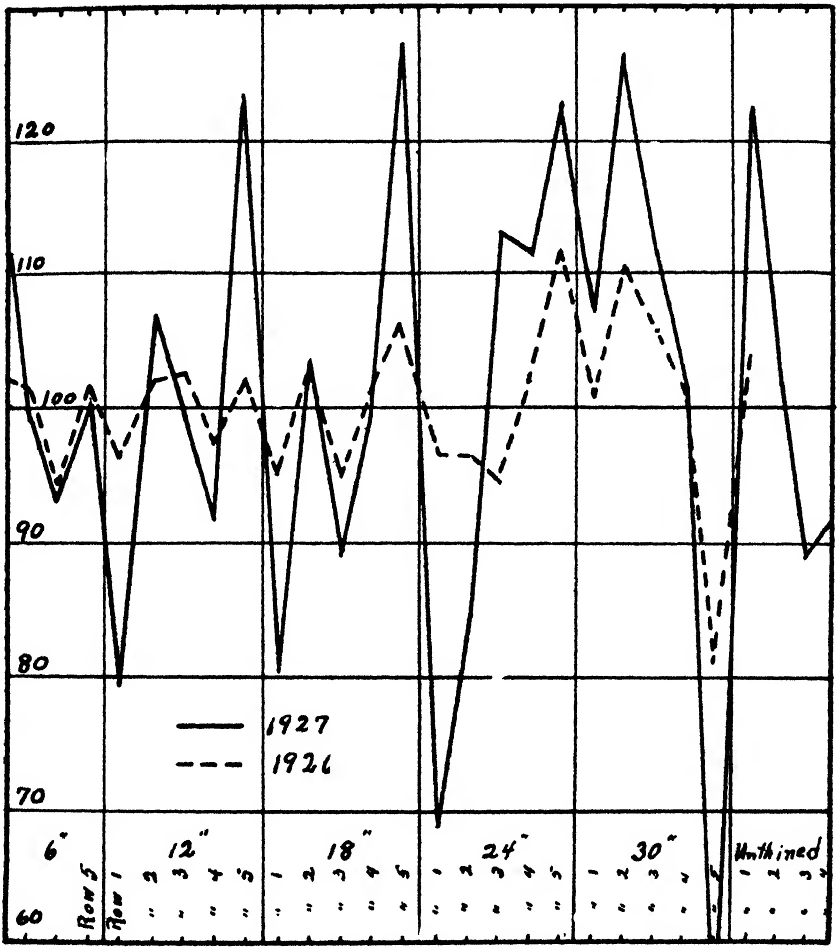

FIG. 3.—Showing yields of individual rows of Blackhull kafir in spacing tests of 1926 and 1927.

It will be seen from Table 13 and Fig. 3 that the yields of the last rows of the denser plantings are in all cases above the average (100%), while the adjacent rows of the less dense spacings are in all cases below average, with the exception of the 30-inch spacing plat. When rows of the 24- and 30-inch spacing grow adjacent to each other, there is less evidence of competition as would be expected.

TABLE 13.—*Comparative yields of individual rows expressed on a percentage basis, rate of planting test with Blackhull kafir, 1926 and 1927.*

Spacing	Row 1	Row 2	Row 3	Row 4	Row 5
		1926			
6 inches	101.3	101.4	101.3	94.4	101.6
12 inches	96.3	101 8	102.5	97.5	101.8
18 inches	95.1	102.5	94.9	101.0	106.6
24 inches	96.5	96.4	93.7	101.9	111.5
30 inches	100.8	110.4	106.5	100.7	81 2
		1927			
6 inches	95 5	111.1	99.2	93.4	100.8
12 inches	79.7	106.9	99.1	91.2	123.8
18 inches	80.5	103.4	89.2	99.6	127.3
24 inches	68.9	84.0	113.0	111.2	122.8
30 inches	107.3	126.5	112.6	101.3	52.3
Unthinned	122.5	101.7	88.7	91.3	95.8

The reason for the strong competition between adjacent rows of plats from a dense to a less dense spacing becomes quite apparent from a consideration of Table 14 and Fig. 4. Forage weights are given in tons per acre of air-dried material.

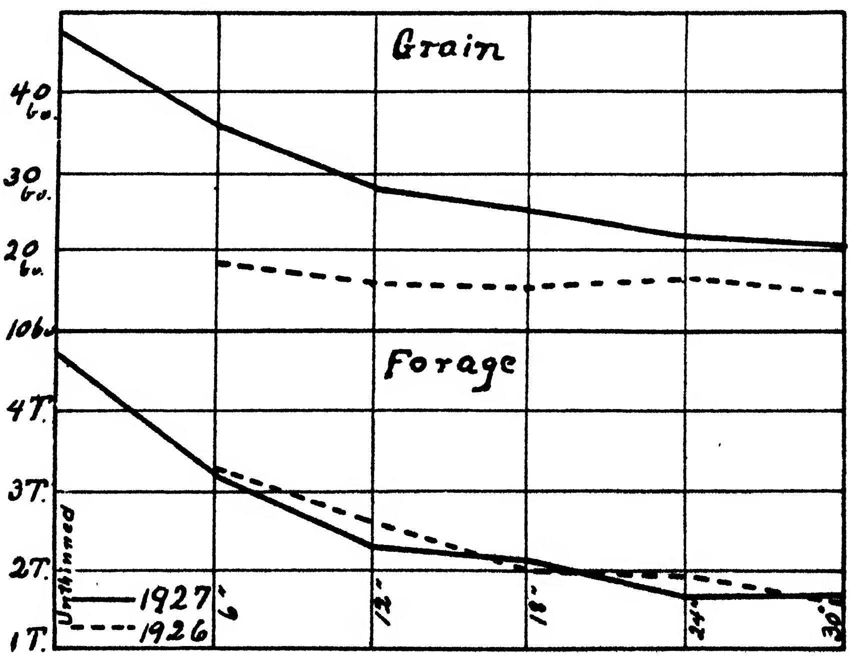

FIG. 4.—Showing relation of distance of spacing in the row to yield of Blackhull kafir in 1926 and 1927.

TABLE 14.—*Relation of distance of spacing in the row to yield of Blackhull kafir.*

	1926		1927	
Spacing in rows in inches	Grain in bushels per acre	Forage in tons per acre	Grain in bushels per acre	Forage in tons per acre
Unthinned	——	——	47.4	4.72
6	18.0	3.25	35.7	3.20
12	15.6	2.62	28.0	2.33
18	14.8	2.01	25.0	2.13
24	16.3	1.92	21.0	1.67
30	14.4	1.56	20.0	1.66

The yields of both grain and forage decreased materially from the thicker to the thinner spacing. The decrease was more rapid in 1927 than in 1926. The differences in the yields of individual rows of adjacent plats were greater in 1927 than in the previous year. The extremely dry season of 1926 may have served to restrict the root systems of the plants to the extent that they did not interfere much with those of adjacent rows.

In both years, the rate of decrease from the dense to the less dense spacings became less as the more distant spacings are reached. This accounts for the behavior of the adjacent rows of the 24- and 30-inch spacing plats.

SUMMARY AND CONCLUSIONS

Two years' data are presented on the comparative yields of individual rows of five-row plats of sorghums in variety tests in an endeavor to find to what degree yields of adjacent varieties are influenced by competition and to find whether or not border rows are essential to the accuracy of variety tests under conditions prevailing at the Oklahoma Agricultural Experiment Station.

The yields of individual rows did not differ significantly from the average yields of the inside rows protected from intervarietal competition or from the average yields of all five rows of the plats. Neither the yields of single rows nor those of combinations of rows showed significant differences.

The outside rows of plats in the variety tests exhibited a somewhat higher degree of variability than did inside rows. Combinations of rows show a slightly lower degree of variability than single rows, as would be expected. The differences in the values of the standard deviations of the respective rows or combination of rows were not consistent. In the greater number of cases, they were not of sufficient magnitude to be significant.

There was a tendency towards a higher degree of variability in the yields of respective rows in the earliest and latest dates of planting.

Such greater variations may be expected as varieties are planted at times removed from their respective optimum dates of planting.

The individual yields of the two outside rows of plats in variety tests and the yields of all inside rows show a high degree of correlation. The values of the coefficients of correlation in no case differed significantly for the same set of outside rows when correlated with the yields of the respective inside rows of plats. This shows that the two respective outside rows of the plats were influenced either in like manner or not at all by rows of adjacent plats.

A marked degree of competition was found in spacing tests. The yields of rows of dense stands profit at the expense of yields of adjacent rows of thinner stands. The degree of competition is affected by environmental conditions.

All data presented lead to the conclusion that single-row plats replicated frequently enough will give as reliable results as will plats with a larger number of rows repeated less frequently. In the utilization of single-row plats care must be exercised in the selection of varieties to grow next to each other. Extreme differences in growing habits must be avoided. Results of the spacing tests serve to emphasize the importance of uniformity of stands to the accuracy of variety tests.

WHEAT, SOYBEAN, AND OAT GERMINATION STUDIES WITH PARTICULAR REFERENCE TO TEMPERATURE RELATIONSHIPS[1]

Harold K. Wilson[2]

INTRODUCTION

Probably no part of the life cycle of a crop plant is more important than the germination phase. With this thought in mind the present investigation was planned to determine the optimum temperature requirements for the germination of wheat (*Triticum vulgare*), soybeans (*Soja max*), and oats (*Avena sativa*). As the experiments were limited to the temperature aspect, it is believed that the studies have progressed far enough to warrant conclusions contributing to a better understanding of germinative phenomena in relation to temperature.

MATERIALS AND METHODS

To give the investigation breadth of scope, seeds were obtained from states having different environmental conditions during the development of the crop. This gave opportunity to study the effect of climatic conditions on seeds of supposedly uniform genetic constitution. The seed of self-fertilized crops was chosen since it was believed that it would most likely be found true to variety name even when grown in different sections of the United States. The following representative varieties were chosen from the three most important market classes of wheat: Turkey—hard red winter, Red Rock—soft red winter, and Marquis—hard red spring. These varieties are sufficiently well known to render a discussion of their characteristics unnecessary.

The Manchu, Virginia, and Wilson varieties of soybeans were selected as representatives of yellow, brown, and black-seeded beans, respectively.

Inability to secure sufficient material made it necessary to limit the oat studies to Silvermine, a large, late, white-glumed variety of considerable merit.

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Splendid cooperation from the various agricultural experiment stations made it possible to collect the seeds for these experiments. Table 1 gives the source of seed samples of each variety.

TABLE 1.—*Source of seed samples.*

Crop	Variety	States furnishing samples
Wheat	Turkey	Utah, Washington, New Mexico, Kansas, Illinois, Kentucky
	Red Rock	Illinois, Indiana, Kentucky, New Jersey, Virginia
	Marquis	Utah, Washington, New Mexico, Indiana, North Dakota, Illinois, Wisconsin
Soybean	Manchu	Iowa, Illinois, North Carolina, Delaware, Kentucky, Indiana, Kansas
	Virginia	Iowa, Illinois, North Carolina, Maryland, Missouri, Pennsylvania
	Wilson	Iowa, Illinois, North Carolina, Delaware, Maryland, Missouri
Oats	Silvermine	Iowa, Illinois, Montana, West Virginia, Virginia, Indiana

Table 1 shows the widespread distribution of the sources of seed samples used. The range of distribution was limited only by the ability of the experiment stations of the country to furnish samples of the desired varieties. Following the work in 1925 a new supply of seed was obtained in 1926 from the same states in order to check the results of the previous year. Unfortunately, unfavorable climatic conditions in many states prevented the proper maturity of soybeans in 1926, thus making it impossible to repeat the work with this crop. However, the wheat and oat tests cover a period of two years.

All germination tests were made in automatically controlled temperature cases in the Plant Physiology Research Laboratories of Dr. Chas. F. Hottes, Urbana, Illinois. The cases were maintained at constant temperatures of 10°, 15°, 20°, 25°, and 30°C. The control apparatus maintained very uniform temperatures.

All seeds were germinated on 6 cm square plaster of paris blocks providing ample space for 100 seeds to be used in each test. Hopkins (13)[3] reports that plaster of paris block provides one of the most satisfactory of germinating substrata. This is in agreement with the findings of the author (28). The blocks were placed in water in metal germinating chambers providing ample space for the germination of six lots of seed under uniform conditions of temperature and moisture.

In every instance tests were repeated and the two tests were germinated at different times. Stevens (27) has stated that duplicate

[3]Reference by number is to "Literature Cited," p. 617.

tests germinated at the same time and under exactly the same conditions are of value only in so far as the numbers are increased. He believed that the same effect would be obtained by placing the total number of seeds in one test. Bailey (2) writes, "One test cannot be accepted as a true measure of any sample of seed." These ideas were accepted as correct and, in the present experiments, each test was repeated as previously stated.

Daily observations were made and notes were taken on the rapidity and vigor of germination as well as on the development of molds.

In germinative studies it is necessary to set up certain standards regarding the meaning of the word germination. One of the earliest investigators of germination, de Candolle (7) writes, "J'ai considere comme le moment de la germination celui ou le spermoderme etant brise, la radicule commence a sortir." It is rather difficult to accept de Candolle's definition of germination for several reasons. In the present investigations it was found that often, even though the seedcoat was broken and the radicle had commenced to emerge, further development was arrested. In the germination of monocotyledonous seeds, a radicle may be produced without an accompanying plumule, and vice versa. Bailey (2) believes that the term sprout is preferable to the word germinate, as germination is complete only when the plantlet has formed its true leaves and has begun to assimilate. However, from the practical standpoint, it is seldom feasible to permit the process to reach this stage. The important thing is that the reader may understand the investigator's technic and thus be able to draw his own conclusions. In this paper, a monocotyledonous seed was credited with germination when it had developed both a radicle and a plumule approximately 3 mm in length. A sprout of about 5 mm was used as a standard for soybean germination.

Initial germination refers to the period when the first seed on any particular block had germinated. Complete germination signifies the stage reached when there was no further increase in the number of seeds germinating.

RESULTS AND THEIR INTERPRETATION

Czapek (6) has stated that the chemical reactions in plants follow the van't Hoff law for chemical reactions, namely, that with an increase in temperature of 10° C there is a doubling of the reaction rate. In an earlier report (28), attention was called to the apparent ease with which the van't Hoff principle might be applied to germination at different temperatures. In the present work, this was especially true of the wheat varieties tested. In each case, with a single exception, an increase of 10° in temperature resulted in a

doubling of the rate of initial germination. Table 2 shows the time required for initial and complete germination of each of the various crops tested. These results are in surprisingly close agreement with the van't Hoff principle.

TABLE 2.—*Number of days required for initial germination of wheat, soybeans, and oats, averages of all varieties for two years, 1925 and 1926.*

Temperature, degrees C	Number of days required for					
	Initial germination			Complete germination		
	Wheat	Oats	Soybeans	Wheat	Oats	Soybeans
10	5.0	5.0	6.0	11.0	10.5	12.0
15	4.0	3.0	4.0	10.0	9.5	8.5
20	2.5	2.5	2.0	6.5	6.0	6.0
25	2.0	2.0	1.0	4.0	4.0	3.5
30	1.0	2.0	1.0	4.0	4.0	3.0

Stevens (27) has suggested that the time for germination tests might well be cut to one-half that in common use; that a period of 4 days for clovers, 5 for timothy, 6 for Brome grass, and 14 for bluegrass is sufficient. Bialoblocki (3), working with constant soil temperatures, reported that in a soil held at a constant temperature of 10°C, wheat plants first appeared five days after planting and that 100% of the plants had appeared above the soil surface in seven days. These figures indicate a shorter time required for both germination and emergence than was required for germination in the present investigations (Table 2). It is readily apparent that the length of the germination period must be in inverse relationship to the temperature employed.

LOW TEMPERATURES OPTIMUM FOR WHEAT GERMINATION

The wheat germination results reported in this paper are in close agreement with those reported from an earlier investigation (28) in which it was found that temperatures of 10°, 15°, and 20°C were best suited for obtaining the maximum germination of wheat. Tables 3, 4, and 5 give the germination of Turkey, Red Rock, and Marquis wheats at the several constant temperatures.

It is evident that each variety of wheat germinated best at the lower temperatures. Although each variety gave lower germination at higher temperatures, there was a decided decrease in the case of Turkey when a temperature of 30° was used. With the exception of one lot of Kansas-grown seed of the 1925 crop, all Turkey samples germinated less than 90% at 30° (Table 3). The seed which germinated better than 90% at a temperature of 15° performed poorly when placed in the 30° temperature case. Although there was a rather uniform decrease in germination percentage as temperatures above 15° were employed, the drop was especially marked between the temperatures of 25° and 30°.

TABLE 3.—*Percentage germination of 1925 and 1926 crops of Turkey wheat grown in various states and germinated at the temperatures indicated.*

Source	10°C 1925	10°C 1926	10°C Avg.	15°C 1925	15°C 1926	15°C Avg.	20°C 1925	20°C 1926	20°C Avg.	25°C 1925	25°C 1926	25°C Avg.	30°C 1925	30°C 1926	30°C Avg.
Utah	94	92	93	94	93	94	91	98	95	89	91	90	76	77	77
Washington	99	94	97	99	100	100	97	94	96	94	71	83	49	21	35
New Mexico	88	87	88	93	92	93	86	88	87	89	81	85	67	67	67
Kansas	98	93	96	98	95	97	98	92	95	94	92	93	91	73	82
Illinois	95	93	94	92	96	94	95	91	93	90	88	89	86	69	78
Kentucky[a]	98	—	—	98	—	—	98	—	—	90	—	—	83	—	—
Average	95	92	94	95	95	95	93	93	93	91	85	88	74	61	68

[a]One year only. Not averaged.

TABLE 4.—*Percentage germination of 1925 and 1926 crops of Red Rock wheat grown in various states and germinated at the temperatures indicated.*

Source	10°C 1925	10°C 1926	10°C Avg.	15°C 1925	15°C 1926	15°C Avg.	20°C 1925	20°C 1926	20°C Avg.	25°C 1925	25°C 1926	25°C Avg.	30°C 1925	30°C 1926	30°C Avg.
Illinois	95	97	96	96	98	97	92	95	94	90	92	91	74	81	78
Indiana	96	89	93	98	92	95	96	94	95	96	95	96	90	85	88
Kentucky	96	95	96	99	98	99	97	96	97	95	92	94	91	90	91
New Jersey	97	94	96	100	97	99	99	94	97	97	93	95	92	91	92
Virginia	87	85	86	92	97	95	89	87	88	88	82	85	73	86	80
Average	94	92	93	97	96	97	95	93	94	93	91	92	84	87	86

TABLE 5.—*Percentage germination of 1925 and 1926 crops of Marquis wheat grown in various states and germinated at the temperatures indicated.*

	Percentage germination at														
	10°C			15°C			20°C			25°C			30°C		
Source	1925	1926	Avg.	1925	1926	Avg.	1925	1926	Avg.	1925	1926	Avg.	1925	1926	Avg.
Washington	94	97	96	98	98	98	97	94	96	88	93	91	61	84	73
New Mexico	97	91	94	94	91	93	94	90	92	88	78	83	69	63	66
Illinois	98	91	95	99	97	98	96	92	94	95	76	86	87	64	76
Indiana	96	97	97	99	98	99	99	91	95	97	91	94	91	85	88
North Dakota	93	92	93	97	94	96	95	91	93	92	92	92	87	84	86
Wisconsin	91	88	90	96	97	97	95	96	96	96	95	96	92	88	90
Utah[a]	93	—	—	99	—	—	91	—	—	92	—	—	89	—	—
Average	95	93	94	97	96	97	96	92	94	93	87	90	81	78	80

[a]1925 only, not averaged.

TABLE 6.—*Summary of data showing the influence of temperature on the germination of all lots of wheat tested at the temperatures indicated.*

Variety	Percentage germination at 10°C	15°C	20°C	25°C	30°C
Turkey	93.5	95.0	93.5	88.0	68.5
Red Rock	93.0	96.5	94.0	92.0	86.0
Marquis	94.0	96.5	94.0	90.0	80.0
Average[a]	93.5	96.0	94.0	90.0	78.0

[a]Calculated to nearest one-half per cent.

An examination of the germination results of the individual varieties shows some differences. As has been suggested, Turkey reacted the least favorably of the three varieties at a temperature of 30°. On an average, increasing the temperature from 25° to 30° lowered the germination percentage 19.5 (Table 6). Red Rock germination decreased only 6% when the germinating temperature was increased from 25° to 30°, while Marquis decreased 10% under the same conditions. These results show that Turkey differed from Red Rock and Marquis to the extent that its seed germinated poorly at the higher temperatures.

While there was but little difference in the averages of total germination at 10° as compared with 15° (Table 6), the time saved in completing a test (Table 2) is slightly in favor of the higher temperature. Also, it is much easier to maintain a temperature of 15° than one of 10°.

Detmer (8) gave the optimum temperature for wheat and oat germination as lying between 25° and 31°C. Haberlandt (10) reported 100% germination of wheat with a temperature of 25° Reaumur (31.25°C) in 48 hours. Duggar (9) cites Haberlandt as giving 29°C as optimum for wheat germination, while Sachs (24) reported 23°R (28.75°C) as most favorable. Kling (15) states that a constant temperature of 30°C is unsuited for grass seed germination. Newcombe (19) found a temperature of 30°C to provide optimum conditions for the growth of wheat coleoptiles. Percival (22) believed 22°C to be optimum for wheat germination. Atterberg (1) reports a temperature of 17°C, while Malsbury (16), working with six varieties of Illinois-grown wheat, found a temperature of 15°C to be the most satisfactory.

Wilson and Hottes (28) reported temperatures of 10° and 15°C as about equally favorable for the highest percentage of wheat germination. It may appear that a temperature of 20° might be employed to advantage as the average germination secured was but little below that obtained at 15°. This is no doubt true in some cases. However, the lower temperature comes nearer to being the same as the soil

temperature under average field conditions at the time of sowing either winter or spring wheat, and for this reason is preferred as it places the test on a basis more nearly approximating natural conditions.

The data presented in Tables 3, 4, 5, and 6 point to the importance of using lower temperatures than are commonly used in seed testing laboratories in order to secure a true measure of the germinating power of a wheat sample.

Harrington (12) reported that temperatures of 17.5°, 20.0°, and 30.0°C usually increased the rapidity of germination of flower seeds, while comparatively low temperatures favored the highest percentage of germination. He also noted that optimum temperatures gave greater opportunity to compare the vigor of different lots of seed. The results reported in this paper agree with these findings.

Data in Tables 3, 4, and 5 indicate that the part of the United States in which the sample was grown had little or no significant influence upon the germinating behavior at the temperatures employed. Schimper (25) believed that the cardinal points of germination were higher for seeds of plants from warm countries than for those from cold sections. Haberlandt (11), in a study of the lower and upper temperature limits for the germination of seeds of plants from warm climates, concluded that, "Optima und Maxima sind also nicht auffallend von den Gleichen, fur die einheimschen Culturpflanzen festgestellen Werthen verschieden, die Minima legen aber in Allgemeinen bedeutend hoher."

The present results indicated no significant differences in the optimum temperatures for the germination of wheat grown in one state as contrasted with the germination of wheat grown in another state. Although the area represented was not so great as in the case mentioned by Haberlandt (11), the principles are much the same in both instances. It is probable, therefore, that wheat grown at different points in an area the size of the United States has the same temperature requirements for optimum germination.

A comparison of the three representative varieties of each of the major market classes of wheat, *viz.*, hard red winter, soft red winter, and hard red spring, shows that, with but one exception, each reacted in the same general manner to the temperatures employed (Table 6). Turkey wheat was more unfavorably affected by a temperature of 30° than were the two other varieties. This behavior of Turkey appeared to be a varietal characteristic.

In an earlier paper (28) attention was called to the striking decrease in the percentage of germination occasioned when Worlds Champion wheat was subjected to a temperature of 30°. This variety is a selection of, and is identical with, Turkey according to Clark, Martin, and Ball (5). If this is true, it appears that the failure of Turkey to germinate well at 30° is very probably due to innate characteristics. Previously (28), a sample of the 1924 crop of Worlds Champion wheat from Illinois was reported to have germinated as follows: 95% at 10°, 92% at 15°, and 89% at 20°C. However, when a temperature of 30° was used, the germination averaged only 21%. Samples of the 1925 and 1926 crops of Worlds Champion grown at the Illinois Agricultural Experiment Station have shown the same marked decrease in percentage of germination at a temperature of 30°. The seed of the 1925 crop germinated 95% at 15° and 25% at 30°. The percentage germination of seed produced in 1926 was 98 at 15° and 51 at 30°. It cannot be said that these characteristics of Turkey wheats are typical of all hard red winter varieties, since the number of varieties tested is too few to justify such a sweeping conclusion. Any differences shown may be credited to varietal characteristics and not to any relationship to the particular market class in which the variety may be grouped.

A condition of dormancy has been suggested as being responsible for the poor performance of Worlds Champion wheat at a temperature of 30° (28). Recent experimental work has shown that a condition of dormancy is probably one of the causes of the low germination of Turkey wheats at 30°. The similar, though sometimes less striking, behavior of all lots of Turkey wheats (Table 3) tends to substantiate the statement that, in general, the Turkey wheats are likely to exhibit a low percentage of germination at a temperature of 30°C. Through pre-cooling of the seed it has been possible to obtain almost perfect germination at the high temperature. However, these results involve a number of considerations which cannot be discussed here. Further investigations are in progress and a separate paper dealing exclusively with the question of dormancy in Turkey wheats is now in the process of preparation.

GROWTH OF FUNGI ON GERMINATING WHEAT VARIES DIRECTLY WITH INCREASE IN TEMPERATURE

The prevalence of mold attack increased markedly from the lower to the higher temperatures as shown in Tables 7 and 8. It was apparent that the molds found more nearly optimum conditions for development at the higher than at the lower temperatures. It is quite

probable that food supplies were in a more readily available form for their use. The higher temperatures were less favorable for the wheat and rendered the embryonic plants more susceptible to fungal attack. The results of the wheat germination previously reported show a lessened percentage of germination in most cases when the temperature was higher than 15°. As might be expected, there existed an inverse relationship between the total germination and the number of moldy kernels failing to germinate.

Mold development is markedly encouraged by seed-coat injuries. A slight break in the membrane beneath the seed-coat provides excellent opportunity for the fungus to gain entrance to the food stored within the seed as has been shown by Hurd (14), Myers (18), Melhus and Durrell (17), and others. These injuries are usually due to threshing operations according to Nobbe (20), Zundel (29), and others. Further, it is probable that the higher temperatures, being unfavorable for best germination, caused a weakening of the seedling. Following this weakening there was a loss of organic materials through the breaks in the membranes of the seed. The molds found this organic matter to be excellent media for their growth and the result was a competition between the fungus and the weakened seedling, each striving to obtain the energy stored within the endosperm. When the wheats were placed under the more unfavorable conditions of high temperature, as 30°, they met with greater compe-

TABLE 7.—*Percentage of moldy wheat kernels failing to germinate at the temperatures indicated, 1925 and 1926 crops.*

Variety	Source	Percentage of moldy kernels at 10°C	15°C	20°C	25°C	30°C
Turkey	Utah	1	3	5	10	24
	Washington	0	1	2	14	24
	New Mexico	2	3	7	10	32
	Kansas	0	1	1	5	9
	Illinois	1	2	2	8	14
	Kentucky	0	3	2	9	10
Red Rock	Illinois	1	0	2	5	18
	Indiana	1	1	2	4	10
	Kentucky	1	0	2	6	9
	New Jersey	2	1	0	4	6
	Virginia	5	1	3	13	17
Marquis	Washington	0	1	2	9	27
	New Mexico	0	2	2	15	29
	Illinois	1	2	3	12	23
	Indiana	0	0	1	5	11
	North Dakota	2	3	2	6	13
	Wisconsin	1	1	2	4	8
	Utah[a]	0	1	5	7	11

[a]1925 only.

tition from the molds with a resulting increase in the percentage of moldy kernels failing to germinate (Tables 7 and 8). As a temperature of 30° approaches the maximum for wheat germination, it is probable that the heat was injurious to the protoplast of the seed and tended to render the membranes permeable, thus permitting the escape of nutrients which were attacked by the molds.

Apparently, there was but little difference between the three wheat varieties in regard to the injuries from mold attack. Turkey and Marquis were attacked to practically the same extent, while Red Rock showed somewhat less infection at the higher temperatures. With each variety the degree of infection increased as the temperature was raised to a maximum of 30°.

TABLE 8.—*Percentage of moldy kernels of all wheat varieties tested failing to germinate at the temperatures indicated, 1925 and 1926 crops.*

Variety	Percentage moldy kernels at 10°C	15°C	20°C	25°C	30°C
Turkey	1	2	3	9	19
Red Rock	2	1	2	6	12
Marquis	1	1	2	8	19
Average	1	1	2	8	17

SOYBEAN GERMINATES WELL THROUGHOUT SERIES OF TEMPERATURES USED

The statement is frequently made that the soybean requires a comparatively high temperature for a satisfactory germination test. Sachs (24) believed that the minimum temperature for soybean germination was about 10°C as contrasted with a minimum of 5°C for wheat. In most cases higher temperatures are employed in making soybean germination tests than are thought to be best for wheat. However, the data given in Tables 9, 10, and 11 indicate that this is probably not necessary. In some instances, as in the

TABLE 9.—*Percentage germination of the 1925 crop of Manchu soybeans grown in different states and the percentage of moldy kernels failing to germinate at the temperature indicated.*

Source	Percentage germination at 10°C	15°C	20°C	25°C	30°C	Percentage moldy kernels at 10°C	15°C	20°C	25°C	30°C
Iowa	98	96	100	97	96	0	2	0	3	2
Illinois	98	100	99	99	99	0	0	1	0	0
N. Carolina	86	89	91	94	89	4	1	2	1	3
Delaware	100	100	100	99	100	0	0	0	1	0
Kentucky	95	95	96	92	92	2	3	2	6	7
Indiana	98	100	98	98	99	0	0	1	1	0
Kansas	90	95	98	97	96	1	1	1	1	2
Average	95	96	97	97	96	1	1	1	2	2

Iowa-grown Wilson and the Delaware-grown Manchu varieties, germination was 100% at a temperature of 10°C.

TABLE 10.—*Percentage germination of the 1925 crop of Virginia soybeans grown in different states and the percentage of moldy kernels failing to germinate at the temperatures indicated.*

Source	Percentage germination at					Percentage moldy kernels at				
	10°C	15°C	20°C	25°C	30°C	10°C	15°C	20°C	25°C	30°C
Iowa	98	100	100	100	100	0	0	0	0	0
Illinois	97	96	96	98	97	1	2	1	1	1
N. Carolina	66	71	68	72	71	0	0	0	0	1
Maryland	98	100	100	100	100	0	0	0	0	0
Missouri	85	94	95	95	97	3	1	0	2	1
Pennsylvania	87	80	91	89	84	6	14	8	6	14
Average	89	90	92	92	92	2	3	2	2	3

Seed of low viability appeared to give better germination at high than at low temperatures. The Wilson beans from Delaware were of low grade and their germination record was poor (Table 11). Molds were very active on the germinating seeds and almost completely overran each lot tested. Germination was lowest at 10°, and rose with each increase of 5° until a maximum was reached at 25°. As the germination increased there was a corresponding decrease in mold activity. The attack had no direct relationship to increasing temperatures as was true in the germination of wheat, because the range of temperatures did not bring the seed to a point where the vitality was lowered and there was presumably a leaching of organic materials as in wheat. For this reason molds developed only when the vitality of the seed was lowered. It is probable that the soybean functioned normally at each of the five temperatures at which it was germinated. In short, the temperatures employed did not exert any perceivable injurious effects upon the germinating soybean seedlings.

TABLE 11.—*Percentage germination of the 1925 crop of Wilson soybeans grown in different states and the percentage of moldy kernels failing to germinate at the temperatures indicated.*

Source	Percentage germination at					Percentage moldy kernels at				
	10°C	15°C	20°C	25°C	30°C	10°C	15°C	20°C	25°C	30°C
Iowa	100	100	100	100	98	0	0	0	0	1
Illinois	96	97	96	93	95	3	2	3	6	5
N. Carolina	59	72	75	79	79	1	0	9	0	1
Delaware	6	12	19	38	33	93	86	81	61	67
Maryland	91	97	98	98	99	0	0	2	0	1
Missouri	98	95	100	99	97	0	1	0	1	3
Average	75	79	81	85	84	16	15	16	11	13

The summary of the soybean germination data (Table 12) shows that the Manchu variety germinated well at all temperatures but

reached a maximum at 25°. The Virginia and Wilson varieties also gave maximum germination at 25° but failed to maintain the high level of germinating performance shown by the Manchu at all temperatures. The reason for the lower average germination of these two varieties may be attributed in large part to the poor performance of the North Carolina- and Delaware-grown Wilson beans (Table 11) and the mediocre germination records of the North Carolina- and Pennsylvania-grown Virginia soybeans (Table 10). The effect of the low germination of these particular samples was to lower the average germination to a marked degree. With the exception of the samples grown in the states named, the germination record of the other lots was similar to that of the Manchu. As mentioned before, the low germination of the North Carolina seed was due to the high percentage of impermeable seed-coats, while unfavorable weather conditions at harvesting time probably were responsible for the low viability of the samples from Delaware and Pennsylvania.

TABLE 12.—*Summary of data on the influence of temperature on the germination of all soybean samples tested.*

	Percentage germination at				
Variety	10°C	15°C	20°C	25°C	30°C
Manchu	95	96	97	97	96
Virginia	89	90	92	92	92
Wilsom	75	79	81	85	84
Average	86	88	90	91	91

The higher the temperature employed the shorter the time required to complete a germination test. For obvious reasons it is always desirable to make the test within the shortest possible period of time if accuracy is not sacrificed. While a temperature of 20° gave practically the same percentage of germination as 25° (Table 12), the time saved with the higher temperature was 2.5 days (Table 2). Also, as has been shown, a temperature of 25° gave the maximum percentage of germination for all samples tested.

The Wilson and Virginia varieties of soybeans presented the problem of impermeable seed-coats. In the soybean as in many other legumes the percentage of hard seed-coats differs within the variety from year to year and may be due to some extent to the environmental conditions under which the beans are grown. Oathout (21) has shown that the Wilson and other black, as well as brown-seeded, varieties of soybeans are especially likely to show varying percentages of impermeable seed-coats. As might be expected, in the present studies, increases in temperature decreased the percentage of impermeable seed-coats. This was no doubt due to the more rapid imbibitional movement of water at the higher temperatures.

Brown and Worley (4), working with barley, obtained similar results and concluded that water becomes less viscous with the higher temperatures and is thus able to penetrate the seed-coats more freely. Shull (26) does not accept this view. He believes that the velocity of water intake is not an exponential function of temperature, but that at any moment it is an inverse exponential function of the amount of water previously absorbed. Further, he states that any appreciable absorption depends upon the physical structure, chemical composition, and state of aggregation of the colloids.

The North Carolina-grown Wilson and Virginia soybeans showed a very high percentage of impermeable seed-coats. As none of the samples from other states showed any appreciable numbers of hard seed-coats, it appears that the high percentage shown by the two varieties from the same state indicates that this characteristic may have been influenced by the environmental conditions under which the crop was grown.

A survey of the soybean germination data suggests that, within the given temperature limits, germination is not affected by the source of seed. As with wheat, there were no apparent germination differences attributable to the section of the country in which the seed was produced.

PERCENTAGE GERMINATION OF SILVERMINE OATS UNIFORM AT DIFFERENT CONSTANT TEMPERATURES

Oat germination tests were restricted to the Silvermine variety and were made under the conditions set forth above. Samples were obtained from the experiment stations of Iowa, Illinois, Montana, West Virginia, and Indiana (Table 1).

In general, the results of the oat germination tests showed that the Silvermine oat reacted somewhat differently from wheat under the same conditions. There were no significant differences in total percentage of germination at the five temperatures (Table 13). The lower temperatures, 10°, 15°, and 20°C gave slightly better results, but the loss of 2 or 3%, as shown at the higher temperatures of 25° and 30°, cannot be considered of importance. The differences noted were more accentuated in the Montana- and Virginia-grown seed of the 1925 crop (Table 13). However, the apparent superiority of the lower temperatures in the instances named was offset by the germination of the seed produced in 1926. The decrease in percentage germination of the Virginia-grown Silvermine oats of the 1925 crop was rather marked at temperatures of 25° and 30°. However, the results with the 1926 crop showed but little decrease at these

temperatures. It is quite probable that the 1926 data more nearly represent the true relationship as they compare more favorably with the records of samples from other states.

The time saved in completing a germination test of oats was decidedly in favor of the higher temperatures (Table 2). With a germinating temperature of 10°, the time required to complete a test was 10.5 days, while with temperatures of 25° and 30° only 4 days were necessary. Since temperatures of 25° and 30° gave practically the same results as a temperature of 20° and in addition saved two days time, the higher temperatures are to be preferred. It probably makes little or no difference whether the temperature used in oat germination tests is 25° or 30°.

A survey of Table 13 shows that Silvermine oats reacted in the same manner at each of the constant temperatures regardless of the state in which the seed was produced. It is believed that a sufficiently wide range of territory was represented in the oat studies (Table 1) to warrant the preceding statement.

The rather inferior lots of seed secured from Montana and from Virginia in 1925 had but little effect upon the average germination of all samples from the entire group of six states (Table 13).

The same general trend was shown in the germinating behavior of seed produced in 1926 as for that grown in 1925. As might be expected there were some differences in the quality of seed for the two years as no two successive years are likely to present the same favorable or unfavorable conditions for the maturing and harvesting of a crop. In spite of these minor variations, the same general relationships are shown to exist between the germination percentages and the constant temperatures at which the seeds were germinated.

FUNGAL ATTACK OF LITTLE IMPORTANCE IN OAT GERMINATION TESTS

It is probable that the oat is less likely to be attacked by molds at a temperature of 30° than is the case with wheat. The results of the oat tests illustrated much the same condition as was reported for the soybean.

Mold development was of little importance in the series of temperatures at which the oats were germinated. Fungal attack had little if any relationship to the temperatures employed and there was no significant increase in the percentage of moldy kernels failing to germinate as the higher temperatures were used (Table 14). The Virginia-grown oats were more susceptible to fungal attack than was the seed from other states. This was probably due to the rather low vitality of the sample as many of the seeds did not germinate.

TABLE 13.—*Percentage germination of the 1925 and 1926 crops of Silvermine oats grown in different states and germinated at the temperature indicated.*

	Percentage germination at														
	10°C			15°C			20°C			25°C			30°C		
Source	1925	1926	Avg.	1925	1926	Avg.	1925	1926	Avg.	1925	1926	Avg.	1925	1926	Avg.
Iowa	98	94	96	97	97	97	97	98	98	94	96	95	96	92	94
Illinois	98	95	97	99	98	99	97	99	98	98	96	97	99	96	98
Montana	95	95	95	89	96	93	90	95	93	85	93	89	84	92	88
W. Virginia	99	96	98	100	97	99	98	98	98	98	96	97	99	94	97
Virginia	90	91	91	91	97	94	85	94	90	80	95	88	73	88	81
Indiana	96	98	97	99	98	99	96	98	97	99	97	98	98	97	98
Average	96	95	96	96	97	97	94	97	96	92	96	94	92	93	93

TABLE 14.—*Percentage of moldy kernels of Silvermine oats grown in different states in 1925 and 1926 failing to germinate at the temperature indicated.*

	Percentage moldy kernels at														
	10°C			15°C			20°C			25°C			30°C		
Source	1925	1926	Avg.	1925	1926	Avg.	1925	1926	Avg.	1925	1926	Avg.	1925	1926	Avg.
Iowa	1	2	2	0	2	1	1	1	1	4	2	3	1	3	2
Illinois	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1
Montana	1	0	1	1	0	1	1	1	1	2	0	1	3	0	2
W. Virginia	0	0	0	0	2	1	0	0	0	0	2	1	0	3	2
Virginia	3	2	3	3	2	3	2	3	3	10	3	7	6	7	7
Indiana	3	0	2	1	1	1	0	1	1	1	0	1	1	1	1
Average	1	1	1	1	1	1	1	1	1	3	1	2	2	2	2

Also, it is possible that more mold spores were present upon the seeds. Lack of germination was naturally followed by subsequent mold attack and decay.

In the wheat tests, mold development often progressed so rapidly that the germination percentages were lowered at high temperatures partly through the direct competition existing between the weakened embryo of the seed and the invading fungus. However, in the oat as in the soybean, mold development accompanied decay of the non-viable seeds only.

In an earlier section of this paper, attention was called to the prevalence of small breaks in the seed-coats of wheat kernels and the importance of these breaks as points of fungal attack. It should be borne in mind that in the threshing operation the lemma and palea are removed from wheat, while these two coverings remain on the threshed oat kernel. These coverings serve as protection to the oat caryopsis and render the entrance of the fungus less likely. Also, the brittle character of the wheat testa renders it more susceptible to the small cracks and breaks usually designated as threshing injury.

SUMMARY AND CONCLUSIONS

This paper reports studies of the germination of different varieties of three major farm crops—wheat, soybeans, and oats. The wheat varieties tested were Turkey, Red Rock, and Marquis, representatives of the three most important market classes, *viz.*, hard red winter, soft red winter, and hard red spring, respectively. Soybean varieties tested were Manchu, Virginia, and Wilson. Only one variety of oats, the Silvermine, was included. Samples of each variety were obtained from various agricultural experiment stations and germinated on plaster of paris blocks at five constant temperatures of 10°, 15°, 20°, 25°, and 30°C. Not less than 100 seeds were used in making a germination test, and every germination test was repeated. Each of the two tests was performed at different periods of time and not concomitantly. Duplicate tests made at the same time and under identically the same conditions are of value only in so far as the total number of seeds is increased. The same results would be obtained by doubling the number of seeds and performing a single germination test.

In the present investigations, the rate of initial germination of the three crops appeared to conform to the principles of the van't Hoff law for chemical reactions. However, the large number of chemical processes and the biological aspect involved in germination make it

probable that the application of the van't Hoff law is possible largely because of its flexibility.

Wheat, soybeans, and oats required practically the same length of time to complete a germination test. Soybeans required more time than wheat or oats at a temperature of 10°C. At all other temperatures soybeans germinated as soon or in less time than either wheat or oats. Wheat and oats were not significantly different in the number of days required to complete a test.

A temperature of 15° was optimum for the germination of the three varieties of wheat. On an average the percentage of germination was but little lower at either 10° or 20°, although differences were greater in individual cases.

Each wheat variety showed decreased percentage of germination with each temperature above 15°, with the poorest performance at 30°.

Samples of the Turkey variety gave a decidedly decreased percentage of germination at 30°. The Washington-grown sample of the 1926 crop germinated 100% at 15° and only 21% at 30°.

Red Rock and Marquis wheat, on an average, gave about the same percentage germination. Both varieties performed poorly at 30°, although the decreased germination was not so marked as with the Turkey variety.

The cardinal points for the germination of wheat are probably the same for seed produced at any point within the borders of the United States.

Mold attack on germinating wheat increased in direct ratio to the germinating temperature. It was of but little importance at temperatures of 10° and 15°. There was an inverse relationship between the total percentage of germination and the percentage of moldy kernels.

Injuries to the inner membranes of the seed afford excellent opportunity for fungi to gain entrance to the food stored within the wheat kernel. When the mold had started growth, there was direct competition between the embryo of the weakened seed and the fungus, each striving to obtain the energy stored within the endosperm.

It is suggested that a temperature of 30° affects the protoplast of the wheat kernel in a manner which permits the outward leaching of soluble food materials which are readily attacked by ever-present fungi.

Soybeans of good quality germinated approximately as well at the low temperatures of 10° and 15° as at the high temperatures of 25° and 30°. Soybeans showed the same ability as wheat to germinate at temperatures of 10° and 15°.

Manchu, Virginia, and Wilson soybeans showed the same germinating relationship to temperatures of 10°, 15°, 20°, 25°, and 30°.

Soybeans of low viability germinated best at a temperature of 25°.

On an average, there was but little difference in the percentage of germination of soybeans at the five constant temperatures. The time saved in completing a test favored the use of the higher temperatures and it appeared that 25° was optimum for soybean germination.

Apparently, mold attack on the germinating soybean had no relationship to the germinating temperature because the temperatures used were not high enough to weaken the seed. Undoubtedly, the maximum germination temperature for the soybean is higher than for wheat. Mold attack on the soybean accompanied the decay processes occurring in the non-viable seeds.

Seeds with impermeable seed-coats occurred in the Virginia and Wilson varieties but not in the Manchu. Bearing in mind the limited studies with the soybean in this investigation, it is suggested that hard seed-coats are most likely to be found in soybean varieties with dark-colored seeds, while yellow varieties rarely show this characteristic.

The impermeability of the soybean seed-coat varied inversely to the germinating temperature. It is probable that the rate of water movement into the seed was accelerated at the higher temperatures because of the lessened viscosity of the water.

Silvermine oats gave practically the same percentage of germination at each of the five temperatures. It is probable that oats will germinate satisfactorily at much higher temperatures than wheat.

The time saved in completing a germination test at the higher temperatures indicates that 25° and 30° temperatures are equally suited to oat germination.

Silvermine oat germination temperature requirements were not affected by the region of the United States in which the sample was produced.

As with soybeans, fungal attack on germinating oats was of little importance and accompanied the decay of non-viable seed. The lemma and palea serve to protect the oat kernel from the injuries in threshing which often occur to wheat.

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TRANSGRESSIVE AND NORMAL SEGREGATIONS IN A CROSS OF MARQUIS X FEDERATION WHEATS[1]

George Stewart and D. C. Tingey[2]

On account of its great commercial importance Marquis wheat has been studied in various crosses. It has yielded a genetically complex series of dwarfs when crossed with Kota and also when crossed with Hard Federation. A peculiar transgressive segregation for awns in a Marquis x Federation cross is herein reported, along with what would seem to be normally expected behavior with reference to color of grain, color of glumes, and dwarfing.

Waldron (5)[3] found in a Kota x Marquis cross normal and dwarf F_3 plants in the ratios of 1:0, 3:1, 13:3, 55:9, 15:1, and 63:1. One series of F_4 families derived from F_2 dwarfs produced ratios of 1:0, 0:1, 1:3, 7:9, 1:15, and 1:63 normal to dwarf plants. Most of his data were explained by a theory of three factors, two of which were for dwarfing. One of them was D(d) and the other A(a) which activated D, both acting as dominants for dwarfing when present in the same genotype. The other was a factor for normal height (Nn) which was completely dominant over both A and D. By this means he explained the possibility of all his ratios except 1:15 and 1:63, which he thought might be accounted for a labile condition bringing about a reversal of dominance.

Goulden (3) followed these studies a step further by studying the cytological behavior of the chromosomes of dwarfs. He found irregular pairing, lagging chromosomes, and trivalents which if applied to dwarfs would explain the 1:15 and 1:63 ratios. This theory would furnish the "labile condition" assumed by Waldron without requiring a reversal of dominance.

Clark (1), in a Hard Federation x Marquis cross, found evidence of the behavior required by the two-factor inhibitor theory for dwarfs. According to this theory one dominant factor for dwarfing allows normal height when a dominant inhibitor is also present. This produces a 13:3 ratio of normal to dwarf in F_1 and 1:0, 13:3, 3:1, 1:3, and 0:1 in F_3. Clark also concluded that there was a two-factor difference in awns between Marquis and Hard Federation. The same study also showed 3:1 ratios for bronze and white glumes, respectively.

[1]Contribution from the Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Approved for publication by the Director, March 5, 1928. Received for publication March 30, 1928.

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[3]Reference by number is to "Literature Cited," p. 634.

EXPERIMENTAL DATA

Marquis wheat, so valuable in the northern Mississippi and Great Plains states and in Canada, fails in yielding ability in the irrigated lands of the Great Basin. It produces good quality grain, and its stiff straw enables it to stand up well in the field. On this account, it was used as one parent in a cross with Federation, which yields satisfactorily and stands well in the field, but has undesirable milling quality.

DESCRIPTION OF PARENTS

Marquis is so well known that mere mention calls its qualities instantly to mind. Lest there be some workers in regions where Marquis is not well known, its principal qualities are summarized. Federation is not yet widely distributed outside of the northern Rocky Mountain region.

Marquis wheat has a spring growth habit, short stiff straw, and a moderately lax spike. The lemmas are nearly but not entirely awnless, being tipped with short, sharp beaks, though occasional apical awns are 1 to 10 mm long. It is officially classified (2) as an awnless wheat. The glumes, which are yellowish white with a few light-bronze streakings, are classified as white. The kernels are short, dark red, and hard for common wheat.

The variety Federation has great commercial importance in Idaho on irrigated land and is now being brought into Utah, where it is replacing the predominant variety Dicklow on land where lodging is bad. Federation has a distinct spring habit, matures somewhat earlier than Dicklow and Marquis and is about 6 to 8 cm shorter of culm than Dicklow and about 4 to 7 cm shorter than Marquis. Its spikes are awnless except for very short tip awns and an occasional apical awn, and the variety is classified (2) as awnless. The spike is somewhat oblong, a trifle more dense than ordinary lax wheats, such as Marquis, and is borne erect. The glumes are dark bronze to brown and the kernels are white, soft, and short.

METHOD OF MAKING OBSERVATIONS

At the Utah Experiment Station, in the summer of 1924, a pure line of Marquis was crossed with a pure line of Federation. The several kernels obtained were seeded in 1925 about a foot apart each way in the field. The plants stooled well and yielded several hundred kernels each. The culms were short. The glumes were bronze and the kernels short and red, very closely resembling Marquis. The lemmas were awnless with a few apical awns not noticeably more pronounced in length than those of Marquis.

Two of the F_1 plants were selected to begin hybrid families. These were designated as 31a and 31b. In the spring of 1926, kernels of each family were sown in rows 1 foot apart each way, spaced 3 or 4 inches apart in the row. The F_2 plants showed segregation for bronze and red glumes, for tall and dwarf plants, for red and white grain, and for lack of awns and short awns 20 to 40 mm in length.

There were 474 F_2 plants in family 31a and 480 in family 31b. The tall plants were classified as to grain and glume color, but since most of the dwarfs bore either no heads or else poorly developed ones, no effort was made to classify them as to other than height characters. A brief summary of the numbers of plants grouped according to F_2 characters is given in Table 1.

TABLE 1.—*Number of F_2 plants in two hybrid families from the cross between Marquis x Federation, classified according to tall or dwarf plants, color of grain, and color of glumes.*

(Families 31a and 31b; grown in 1926 at Logan, Utah.)

Family	Number of tall plants: Red kernels, Bronze glumes	Red kernels, White glumes	White kernels, Bronze glumes	White kernels, White glumes	Number of dwarf plants
31a	274	88	11	9	92
31b	283	100	14	7	76

The data suggested a 15:1 ratio for red and white grain, a 3:1 ratio for bronze and white glumes, and a 13:3 ratio for tall and dwarf plants. Since the F_3 progenies were to be grown for the purpose of obtaining pure lines for rod-row tests, it was decided to secure the necessary F_3 genetic data and to compare the observed data with the calculated expectancies on the basis of the ratio suspected from the F_2 segregations.

Family 31a was chosen for the F_3 planting. On account of too much other material, only alternate plants were chosen at random for parents of F_3 progenies. However, all of the ones with white grain were continued in F_3. Every F_2 plant selected was the parent of an F_3 progeny of 30 to 50 plants. So many of the dwarf plants bore either no kernels or too few to seed good-sized progenies that none of these was continued into F_3.

At harvest all plants were pulled and each separate progeny tied and carefully labeled. In December the plants were classified in the laboratory for awns, for grain color, for glume color, and for tall and dwarf plants. It was now possible to arrive at the genotype of the F_2 plants by the F_3 breeding behavior, and this was taken as the basis of all classifications reported in the following pages. In each case the total progeny of 30 to 50 plants was carefully classified as to awns,

color of grain, color of glumes, and tallness or dwarfness. For example, a given progeny segregated 29 bronze glumes to 8 white glumes. The F_3 breeding behavior of one F_2 plant was thus obtained. This method was followed for every progeny grown and for each character studied.

Since only each alternate F_2 plant had a progeny, the numbers obtained were multiplied by 2, except for the progenies from the 20 F_2 plants with white grain, kernels from all of which were seeded. One white-grained F_2 plant which had been shattered in handling had too few kernels for a progeny row and was not used, though the data for grain color and glume color are included. The reason for departing from the plan of discarding alternate plants in this group was to obtain enough pure lines in this group for yield tests. As it was, there were only 19 progenies in this group, 6 of which segregated for tall and dwarf plants; 8 progenies segregated for glume color; and 9 segregated for awns. Some of these segregating progenies segregated for two or all three of the characters mentioned. Only four were found to be homozygous for all characters, thus bearing out the wisdom of including all the white-grained progenies.

There were actually 200 F_3 progenies grown, 181 of which represented two F_2 plants each (its own parental plant, and the discarded random alternate) and 19 of which represented a single F_2 white-grained plant. The F_3 numbers reported, therefore, were obtained by doubling the actual number of red-grained progenies behaving in a particular fashion and adding to this doubled number the actual number of white-grained progenies behaving in a similar fashion. This accounted for all F_2 plants but counted each one only once. The F_2 data represent observations on the actual F_2 plants, since all were then available.

AWNS

Observations on the F_1 plants did not suggest anything unusual regarding awns. During the next season, however, F_2 plants were observed to vary considerably in the expression of this character. In F_3 each plant in each F_3 progeny was classified in one of three groups as follows:

(a) Nearly awnless, that is, similar to either parent. This group of plants was designated as having awns No. 1.

(b) Distinct short awns, about the size of the awns on ordinary F_1 plants from a cross between awnless and awned varieties. The awns in this group exceeded those of either parent by several hundred per cent. They were real awns, though not long ones, as is shown in Fig. 1. The plants in this group were designated as having awns No. 2.

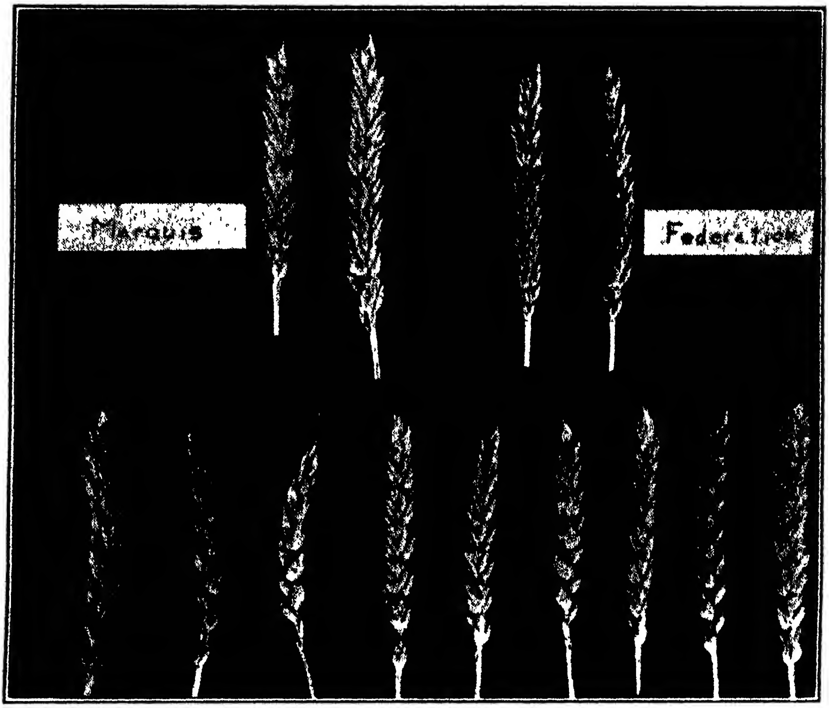

FIG. 1.—Awn development in Marquis and in Federation wheats and in hybrid F_3 lines from a Marquis x Federation cross.

Top left: Range in awn development of the Marquis parent.

Top right: Range in awn development of the Federation parent.

Bottom: Awn development in F_3 lines. The four at the left were homozygous for transgressive greater awn development than that of either parent, whereas the three at the right were homozygous for short awns. The other two were heterozygous and segregated into forms similar to the homozygous short and homozygous long. Involved were one major factor, and some minor factors, causing a variation in development between the homozygous F_3 lines in each of the major groups. A few rare F_3 lines were homozygous for an awn development somewhat similar to that of the F_2 plants which proved to be heterozygous.

(c) Progenies segregating for both sorts of awns.

There were 52 progenies breeding true for awns No. 1 and 50 for awns No. 2, with 98 segregating. This is an unusually close approximation of a 1:2:1 ratio. When the closeness of fit is calculated, $X^2 = 0.12$, which makes P very high. When properly corrected for the planting plan so as to account for all F_2 plants, the numbers were 98:187:96; X^2 is now 0.16 and P is much above 0.50. There seems, therefore, to be a single major factor difference between the two parents. The parent carried some complementary factor without

the presence of which the awns did not develop. However, the inheritance is more complex than this, as some of the group classified as awnless were homozygous for almost no beaks or awn points and others were homozygous for short beaks. In the group that bore awns transgressively longer than either parent (awns No. 2), some progenies that were homozygous bore much more fully developed awns than did other homozygous awned progenies. There were, therefore, three major groups, *viz.*, (a) homozygous for awns No. 1, (b) heterozygous for awns No. 1 and No. 2, and (c) homozygous for awns No. 2. Each of the two homozygous groups, however, consisted of a series of minor groups which the writers were unable to separate into classes accurately enough to permit the study of ratios. The three major groups were clear-cut, however, and readily separated from each other by sharp distinctions. The variations for awns No. 1 did not in the least overlap the variations for awns No. 2. In the homozygous rows there was no question as to where the rows belonged. In the heterozygous rows all plants could not be accurately classified. There were some plants clearly having awns No. 1, some clearly having awns No. 2, and some intermediate which were much more like awns No. 1 than awns No. 2. It is thought that the intermediates would segregate if continued into F_4.

It is definite that progenies true-breeding for awns No. 1 and for awns No. 2 can be easily recognized, and also that segregating rows can be noted with little error if the F_3 breeding behavior of reasonably good-sized progenies is used as the basis of determining the genotype of F_2 plants. Should only a few progeny rows be used in F_3, inaccurate segregation ratios might be expected. When 200 random F_3 progenies are used there should be, according to the laws of chance, rather close approximation to accuracy, which is thought to have been obtained here.

From the standpoint of ratios, this case for transgressive awn segregation is closely analogous to one previously reported by Stewart (4) for inheritance of spike-density. In the case with awns reported here the grandparents, however, were recovered, whereas in the case of spike density one grandparent was either not recovered or else with great infrequency. The other grandparent was occasionally obtained. Therefore, while complicated, the awn inheritance in this Marquis x Federation cross is less complex than the inheritance of spike density in the Sevier x Federation cross previously reported.

COLOR OF GLUMES

The F_1 plants all had dark bronze glumes, practically as dark as the Federation parent. Of the 382 tall F_2 plants, 285 had bronze glumes

and 97 had white glumes. This is a deviation of only 2 plants from a 3:1 ratio, when the probable error is 5.71 plants. The 200 F_3 progenies showed an almost equally close fit to a 1:2:1 ratio. There were 46 progenies with true-breeding red glumes, 55 with true-breeding white glumes, and 99 segregating, where 50, 100, and 50 is the calculated expectancy. For these numbers $X^2 = 0.83$, and P is considerably higher than 0.50.

The data fit very closely the theory of one major dominant factor difference for the color of glumes.

COLOR OF GRAIN

The F_1 plants all bore dark red kernels, similar in size and in general appearance to those of Marquis. In the F_2 generation, 362 plants had red grain and 20 had white grain. Out of 382 plants, 23.9 would be expected to have white grain on a basis of 15 red:1 white. Since the F_3 breeding behavior shows much more about the genotype of an F_2 plant than can possibly be told by inspection of the F_2 plant itself, final decision as to proper classification was left until the F_3 progenies were grown. The approximation of a 15:1 ratio suggests a two-factor difference for color of grain. This would give, in F_3, four groups of progenies in the following proportions:

7 true-breeding for red grain
4 segregating 15 red: 1 white
4 segregating 3 red: 1 white
1 true-breeding for white grain

Of the 382 progenies, 172 bred true for red grain; 88 segregated 15 red: 1 white; 102 segregated 3 red: 1 white; and 20 bred true for white grain. The closeness of fit is shown in Table 2.

TABLE 2.—*Closeness of fit of four groups of progenies compared with a 7:4:4:1 segregation on grain color.*

(Family 31a; grown in 1927 at Logan, Utah.)

Group	C	O	C-O	$(C-O)^2$	$\frac{(C-O)^2}{C}$
Homozygous red	167.1	172	4.9	24.01	0.1437
Segregating 15 red: 1 white	95.5	88	7.5	56.25	0.5891
Segregating 3 red: 1 white	95.5	102	6.5	42.25	0.4424
Homozygous white	23.9	20	3.9	15.21	0.6364
					$X^2 = 1.8116$
					$P = 0.6155$

The probability, therefore, is very high that the theory of duplicate factors for red grain color fits the observed facts. In order to study the data for independent or linked assortment of genes for grain color and glume color, a calculation was made of the ratios to be expected

for strictly independent assortment. This combination of grain color and glume color would yield from each 64 progenies 12 groups in the proportions shown in Table 3.

TABLE 3.—*Calculated proportion of 64 progenies to be found in 12 groups on the basis of duplicate factors for grain color and one independent factor for glume color.*

A. True-breeding for red grain
- 7 progenies true-breeding for bronze glumes
- 14 progenies segregating, 3 bronze: 1 white for glume color
- 7 progenies true-breeding for white glumes

B. Segregating 15 red: 1 white for grain color
- 4 progenies true-breeding for bronze glumes
- 8 progenies segregating 3 bronze: 1 white for glume color
- 4 progenies true-breeding for white glumes

C. Segregating 3 red:1 white for grain color
- 4 progenies true-breeding for bronze glumes
- 8 progenies segregating 3 bronze: 1 white for glume color
- 4 progenies true-breeding for white glumes

D. True-breeding for white grain
- 1 progeny true-breeding for bronze glumes
- 2 progenies segregating 3 bronze: 1 white for glume color
- 1 progeny true-breeding for white glumes

Total, 64 progenies

The closeness of fit of the calculated proportions to the observed is shown in Table 4.

In this case $X^2 = 9.7977$, which is rather large, but for 12 classes, as here used, $P = 0.5492$ which is an excellent fit. The chances are that in purely random sampling a worse fit might be expected in 55 cases out of each 100. It is highly probable, therefore, that the theory of two-factor difference (duplicate factors) for grain color and a single-factor difference for glume color, all independently inherited, fit the observed facts very closely.

DWARF PLANTS

There were 92 dwarf plants in family 31a and 76 in family 31b. This is a ratio of 12.89:3.11 of tall to dwarf plants and of 13.49:2.51 for the two families when a 13:3 ratio might have been expected from those previous crosses with Marquis in which dwarfs were obtained.

In the family 31a with 474 total plants, this is a deviation of 3.5 plants when the probable error is 5.72. This deviation is, therefore, not significant. In family 31b with 480 total plants, 76 dwarfs is a deviation of 14 plants, with a probable error of 5.77 plants. The deviation is 2.4 times its probable error. A wider deviation due to chance alone could occur once in about 11 times, which after all is moderately frequent. This theory for explaining the inheritance of dwarfness

TABLE 4.—*Closeness of fit of 12 groups of observed (O) progenies compared with the calculated (C) expectancy on the basis of duplicate factors for grain color and one factor for glume color, all independently assorted, calculated from ratios shown in Table 3.*

(Family 31a; grown in 1927 at Logan, Utah.)

	C	O	C-O	$(C-O)^2$	$\frac{(C-O)^2}{C}$
1. True-breeding red grain; true-breeding bronze glumes	42	46	4	16	0.3810
2. True-breeding red grain; segregating 3:1 for glume color	84	84	0		
3. True-breeding red grain; true-breeding white glumes	42	42	0		
4. Segregating 15:1 for grain color; true-breeding bronze glumes	24	20	4	16	0.6667
5. Segregating 15:1 for grain color; segregating 3:1 for glume color	48	50	2	4	0.0833
6. Segregating 15:1 for grain color; true-breeding for white glumes	24	18	6	36	1.5000
7. Segregating 3:1 for grain color; true-breeding for bronze glumes	24	22	2	4	0.1667
8. Segregating 3:1 for grain color; segregating 3:1 for glume color	48	48			
9. Segregating 3:1 for grain color; true-breeding for white glumes	24	32	8	64	2.6667
10. True-breeding for white grain; true-breeding for bronze glumes	6	3	3	9	1.5000
11. True-breeding for white grain; segregating 3:1 for glume color	12	8	4	16	1.3333
12. True-breeding for white grain; true-breeding for white glumes	6	9	3	9	1.5000
					$X^2 = 9.7977$
					$P = 0.5492$

involves two factors, *viz.*, (a) D (d) which in the dominant condition produces dwarf plants either when homozygous or heterozygous; and (b) I (i) an inhibiting factor which prevents the expression of dwarfness when the dominant I is present either in the homozygous or in the heterozygous condition.

There would be in F_2, according to this theory, two phenotypes—tall and dwarf—which would behave in F_3 as shown below:

Marquis IIDD x Federation iidd F_1 IiDd (tall plants)

F_2 Generation

Tall Plants

1 IIDD (tall in F_2; tall in F_3)
2 IIDd (tall in F_2; tall in F_3)
2 IiDD (tall in F_2; segregate 3 tall: 1 dwarf in F_3)
4 IiDd (tall in F_2; segregate 13 tall: 3 dwarf in F_3)

1 IIdd (tall in F_2; tall in F_3)
2 Iidd (tall in F_2; tall in F_3)
1 iidd (tall in F_2; tall in F_3)

Dwarf Plants

1 iiDD (dwarf in F_2; dwarf in F_3)
2 iiDd (dwarf in F_2; segregate 3 dwarf: 1 tall in F_3)

In F_3 no progeny rows were seeded with grain from dwarf plants. The progeny rows from tall plants, however, segregated in such a fashion as to show which tall plants were breeding true for tall plants and which were segregating. According to the inhibitor theory just explained, one-third of the dwarfs should breed true and two-thirds should segregate 3 dwarf: 1 tall. Since the F_2 dwarfs were not continued in F_3, these two classes could not be separated. If these dwarfs be regarded as a unit, the genotypes can be checked. The expectation based on the breeding behavior of F_3 plants would be as follows:

7 true-breeding for tall plants
4 segregating 13 tall: 3 dwarf
2 segregating 3 tall: 1 dwarf
3 dwarf plants (not continued in F_3)

The F_3 breeding behavior permitted a reasonably accurate determination of these groupings. Entire absence of dwarfs in certain progenies clearly designated these as being homozygous for tall plants. The dwarfs obtained in F_2 are combined into one class and regarded as merely dwarfs

The 13:3 and 3:1 ratios, expected from two groups of tall plants, approximate each other so closely as to cause difficulty in classifying the progenies. The classification was made in a somewhat arbitrary fashion by calculating the goodness of fit in terms of deviation (Dev.) divided by the probable error (P. E.). Most of the progenies were clearly in either one group or the other, though in the cases of a few intermediates classification was doubtful. Intermediate families were classified as belonging to the 13:3 or to the 3:1 group, accordingly as the ratio Dev./P. E. was smaller for that particular group. In Table 5 are given the progenies so classified, together with their deviations and the ratio of the deviations to the probable errors. There were 53 progenies classified as being 13 tall: 3 dwarf and 29 as being 3 tall: 1 dwarf.

In Table 6 is given the number of progenies falling within one, two, three, and four times the probable error based on the deviations from the expected numbers. Instead of the expected 50%, there are 67% of the progenies within the limits of one times the probable error. Such a preponderance of progenies whose deviations from the theo-

TABLE 5.—*Segregation for normal and dwarf plants in F_3 progenies from normal F_2 plants, grouped into two classes according to nature of the segregation of normal to dwarf plants—(a) 13:3 and (b) 3:1.*

(Family 31a; grown in 1927 at Logan, Utah.)

Normal	Dwarf	Calculated	Dev. calc. 13:3	P. E.	Dev./P. E.
31	4	6.56	2.56	1.56	1.64
23	3	4.88	1.88	1.34	1.40
40	6	8.63	2.63	1.79	1.47
12	3	2.81	0.19	1.13	0.17
30	6	6.75	0.75	1.58	0.47
24	6	5.63	0.37	1.44	0.26
22	4	4.88	0.88	1.34	0.47
35	7	8.99	1.99	1.71	1.16
24	1	5.88	4.88	1.32	3.70
29	3	7.11	4.11	1.49	2.76
21	5	4.88	0.12	1.34	0.09
19	4	4.31	0.31	1.26	0.25
28	4	6.00	2.00	1.49	1.34
25	5	5.63	0.63	1.44	0.44
34	4	7.13	3.13	1.62	1.93
34	8	7.88	0.12	1.71	0.07
24	4	5.25	1.25	1.39	0.90
31	4	6.56	2.56	1.56	1.64
36	8	8.25	0.25	1.75	0.14
35	7	7.88	0.88	1.71	0.52
26	6	6.00		1.49	
30	4	6.38	2.38	1.54	1.87
27	5	6.00	1.00	1.65	0.61
29	7	6.75	0.25	1.58	0.16
30	4	6.38	2.38	1.54	1.58
28	1	5.44	4.44	1.42	3.13
27	2	5.44	3.44	1.42	2.42
36	5	7.69	2.69	1.69	1.59
36	6	7.88	1.88	1.89	0.99
35	4	7.31	3.31	1.64	2.02
35	7	7.88	0.88	1.71	0.51
30	5	6.56	1.56	1.56	1.00
11	1	2.25	1.25	0.91	1.34
26	4	5.63	1.63	1.44	1.13
29	5	6.38	1.38	1.54	0.90
30	1	5.81	4.81	1.47	3.27
37	4	5.81	1.81	1.47	1.23
28	4	6.00	2.00	1.49	1.34
29	7	6.75	0.25	1.58	0.16
39	8	8.81	0.81	1.80	0.45
31	5	6.75	1.75	1.58	1.11
31	4	6.56	2.56	1.56	1.64
30	8	7.13	0.87	1.62	0.54
41	9	9.38	0.38	1.86	0.20
40	9	9.18	0.18	1.84	0.10

TABLE 5.—*Concluded.*

Normal	Dwarf	Calculated	Dev. calc. 13:3	P. E.	Dev./P E.
29	7	6.75	0.25	1.58	0.16
21	5	4.88	0.12	1.34	0.09
26	7	6.19	0.81	1.51	0.54
28	7	6.56	0.44	1.56	0.28
23	6	5.44	0.56	1.42	0.39
30	8	7.13	0.87	1.62	0.54
30	7	6.94	0.06	1.60	0.04
31	8	7.31	0.69	1.64	0.42
			Dev. Calc. 3:1		
29	9	9.50	0.50	1.80	0.28
26	9	8.75	0.25	1.73	0.14
30	11	10.25	0.75	1.87	0.40
21	6	6.75	0.75	1.52	0.49
19	6	6.25	0.25	1.46	0.17
20	6	6.50	0.50	1.49	0.34
20	7	6.75	0.25	1.52	0.16
25	10	8.75	1.25	1.56	0.80
26	8	8.50	0 50	1.70	0.29
28	9	9.25	0.25	1.78	0.14
23	8	7.75	0.25	1.63	0.15
24	8	8.00		1.65	
34	11	11.25	0.25	1.96	0 13
16	11	6.75	4.25	1.52	2.80
23	7	7.50	0.50	1.60	0.31
24	9	8 25	0.75	1 68	0.45
19	12	7 75	4.25	1.63	2.61
24	10	8.50	1.50	1.70	0.88
22	7	7.25	0.25	1.57	0.16
15	6	5.25	0.75	1.34	0.56
34	14	12.00	2.00	2.02	0.99
29	8	9.25	1.25	1.78	0.70
23	7	7.50	0.50	1.60	0.31
22	8	7.50	0.50	1.60	0.31
27	10	9.25	0.75	1.78	0.42
28	10	9.50	0.50	1.80	0.28
28	13	10.25	2.75	1.87	1.47
29	14	10.75	3.25	1.92	1.69
29	16	11.25	4.75	1.96	2.42

rectical were within one times the probable error is to be anticipated from the fact that there were deviations wider than one times the probable error in only one direction for each group. This resulted from the arbitrary method of basing the separation on the statistical goodness of fit which eliminated automatically wide variations of each group in the direction of the other group. The total numbers obtained would probably approximate accuracy, due to somewhat equal overlapping, but would prune off half of the wide deviates. In spite of this, there is a rather close approximation to expected percentages in

the limits set up by one, two, three, and four times the probable error.

TABLE 6.—*Number of progenies having deviations from the expected within the limits of one, two, three and four times the probable error (P. E.).*

Within limits of	Number of progenies	Percentage of progenies	Theoretical percentage
1 x P. E.	55	67.1	50.0
2 x P. E.	18	89.0	82.3
3 x P. E.	6	96.3	95.7
4 x P. E.	3	100.0	99.3

When the numbers of progenies in each breeding group are properly corrected, according to the nature of the planting plan, the numbers become 101 which segregated in a ratio of 13:3 and 57 which segregated in a 3:1 ratio. The corrected numbers obtained in all groups are shown in Table 7, from which the goodness of fit is also calculated.

TABLE 7.—*Closeness of fit of four groups of F_2 plants as determined by their F_3 breeding behavior compared with expected numbers according to two-factor inhibitor theory, i. e., a 7:4:2:3 segregation. F_2 dwarfs were not continued in F_3 and consequently not separated into two genotypes.*

(Family 31a; grown in 1927 at Logan, Utah.)

Group	C	O	(C-O)	$(C-O)^2$	$\frac{(C-O)^2}{C}$
Homozygous tall	206.1	221	14.9	222.01	1.0772
Segregating 13 tall: 3 dwarf	117.7	101	16.7	278.89	2.3695
Segregating 3 tall: 1 dwarf	58.9	57	1.9	3.61	0.0613
Dwarfs	88.3	92	3.7	13.69	0.1550
					X^2 = 3.6630
					P = 0.3153

The theory fits the observations so well that in about 32 cases out of 100 wider deviations might be expected due to chance alone.

In view of the likelihood of error in separating the very similar and overlapping segregations in the 13:3 and in the 3:1 expected ratios, it might be well to combine the two segregating classes. The ratio is then 7 true-breeding tall: 6 segregating for tall and dwarf: 3 dwarfs. The closeness of fit on this basis is given in Table 8.

TABLE 8.—*The closeness of fit for three groups of F_2 plants as determined by their F_3 breeding behavior compared with the two-factor inhibitor theory for dwarf plants, i. e., 7:6:3 ratio.*

(Family 31a; grown in 1927 at Logan, Utah.)

Group	C	O	C-O	$(C-O)^2$	$\frac{(C-O)^2}{C}$
Homozygous tall	206.1	221	14.9	222.01	1.0772
Heterozygous for tall and dwarf	176.6	158	18.6	345.96	1.9590
Dwarfs	88.3	92	3.7	13.69	0.1550
					X^2 = 3.1912
					P = 0.2063

When all the segregating progenies are classified into one group, P is about 0.21. In 21 out of 100 cases a worse fit might be expected from chance alone. While not a high fit, it is not a poor one. In fact, the P of 0.21 obtained when these two groups are combined is not far different from that of 0.32 when they were separated. The two P's really substantiate each other. The evidence, therefore, seems to bear out the theory of one dominant factor for dwarfness with a dominant inhibitor preventing its expression.

SUMMARY

In a wheat cross between a pure line of Marquis and a pure line of Federation, both parents were observed to be awnless, though both have short tip awns, Marquis having somewhat longer ones. Marquis has white glumes and red kernels. Both are homozygous for normal height. The F_1 plants were awnless, or nearly so, bronze-glumed, red-kerneled, and normal in height

Two families of F_2 plants consisted of 474 and 480 plants. In F_2 there were 92 and 76 dwarf plants in the two families, 31a and 31b, respectively. Family 31a was continued in F_3, seed from plants of normal height being sown. Seed from every alternate plant of normal height which had red kernels was sown in F_3 progeny rows. There were 20 plants of normal height with white kernels. One of these was accidentally shattered so badly as to lose most of the kernels. Seeds of each of the other 19 were sown in a separate progeny row. In all, 200 F_3 progeny rows were grown, interspersed at intervals with parental rows as checks. The F_3 breeding behavior of each progeny was used to determine the genotype of the F_2 plant from which it was descended, except in the case of the F_2 dwarf plants which were not continued into F_3.

Each plant in each F_3 progeny row was classified as to awn class, color of glumes, color of grain, and height of plant, that is, whether normal or dwarf. The number in each true-breeding or segregating group was corrected according to the planting plan. The number that came from the red-kerneled group in which only alternate plants were used was doubled. To this was added the number obtained from the white-kerneled group, progenies from all of which were grown.

Although both parents are classified as awnless, there were F_3 progenies homozygous for a considerable development of awns, rather similar to that of the F_1 hybrid between a fully-awned variety and an awnless variety of wheat. There were homozygous F_3 progenies of similar awn development to that of Marquis and some of less development similar to that of Federation. Other progenies segre-

gated for beaks and short awns. The homozygous beaked progenies, the heterozygous progenies, and the homozygous awned progenies occurred in the proportions of 98:187:96, which is an extremely close approximation to a 1:2:1 ratio. Since $X^2 = 0.16$, P was much above 0.50.

This transgressive segregation of awns indicates a single major factor difference. Some complementary relationship, however, must be present which permitted the expression of awns. There seem also to be minor factors involved. A similar but more complex case has been previously reported (4) for spike density.

Glume color gave a close fit for a ratio of 3 bronze: 1 white; X^2 was 0.83, and P about 0.75.

The inheritance of grain color was explained by a difference of two (duplicate) factors. In this case P = 0.62.

Glume color and grain color segregated independently, P being 0.55.

The dwarfs apparently followed the 13.3 ratio in F_2 and also gave the proper F_3 behavior for the theory of one dominant factor for dwarfing (Dd) and one dominant inhibiting factor (Ii). The calculated expectancy when compared with the observed gave a P of 0.32, which is a fairly close fit.

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MEASUREMENT OF LEAF AREA USING THE PHOTO-ELECTRIC CELL[1]

R. W. Gerdel and Robt. M. Salter[2]

In a study of the effects of various soil treatments upon the development of corn at the Ohio Experiment Station, the need arose for a rapid and fairly accurate method of measuring the area of a large number of corn leaves. Such a method was developed through the application of the photo-metric properties of the selenium cell. The apparatus and its use are described in the hope that the method may be found useful to others in studies involving the routine measurement of the area of large numbers of leaves or other irregular surfaces.

APPARATUS

The essential features of the apparatus comprise a light-tight cabinet or photometer within which is mounted the selenium cell and having in its upper surface a fairly large plate glass window illuminated from above by means of a balopticon The leaves to be measured are placed upon the glass window and the change in the electrical resistance of the selenium cell, occasioned by the reduced amount of light passing into the cabinet, is measured by a suitable electrical device.

CONSTRUCTION OF PHOTOMETER

The general construction of the photometer is shown in Figs. 1 and 2. It consists of a large cubicle cabinet (Fig. 1, 5) in the top of which occurs a large square opening covered by two glass plates so arranged that the leaves to be measured may be placed between them. Above the cabinet is supported a balopticon (Fig. 1, 6) containing a 400-watt projection bulb. A table beside the cabinet has a lower shelf for the necessary batteries, while upon the top of the table is placed the instrument box, (Fig. 1, 3) in which is assembled the apparatus necessary for measuring the resistance of the photoelectric cell.

The balopticon is supported by a set of pipe standards (Fig. 1, 7) fastened to the wall. The balopticon is attached to these standards by four large burette clamps, thus providing for a vertical adjustment of the entire lantern as well as permitting the focal adjustment of the lantern itself. The pipe standards are so arranged that the projection lens of the lantern is over the exact center of the glass plates in the top of the cabinet. A 20-ohm rheostat of 4 or 5 ampere capacity

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication April 17, 1928.

[2]Assistant and Chief in Agronomy, respectively.

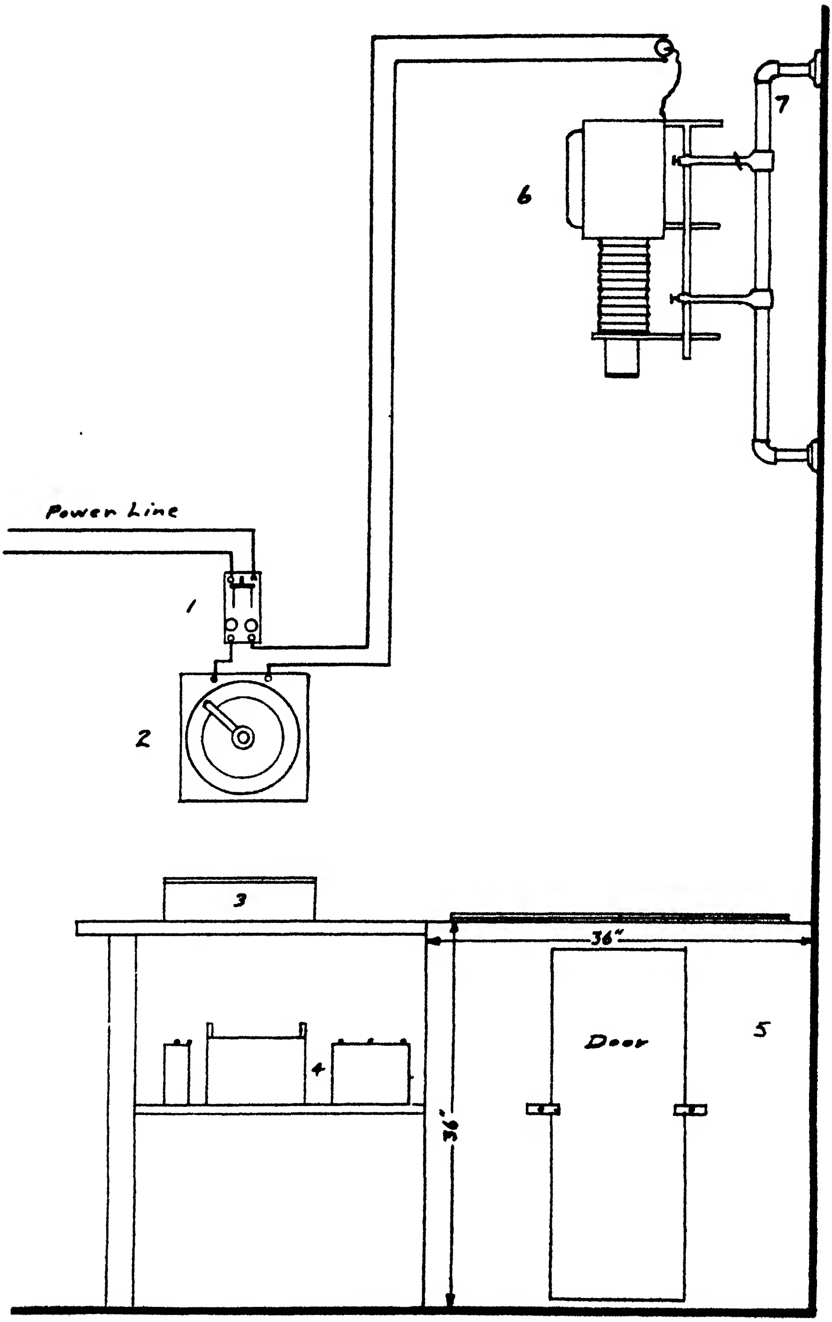

FIG. 1.

(Fig. 1, 2) is connected in series with the balopticon to control voltage fluctuations in the power line. Both lantern and rheostat are connected to the power line through a double knife switch and fuse box (Fig. 1, 1).

The construction details for the cabinet are shown in Fig. 2. It consists of a cube, 36 inches on a side, with a 20-inch opening in the top. This opening is constructed at a 45° angle to the sides of the

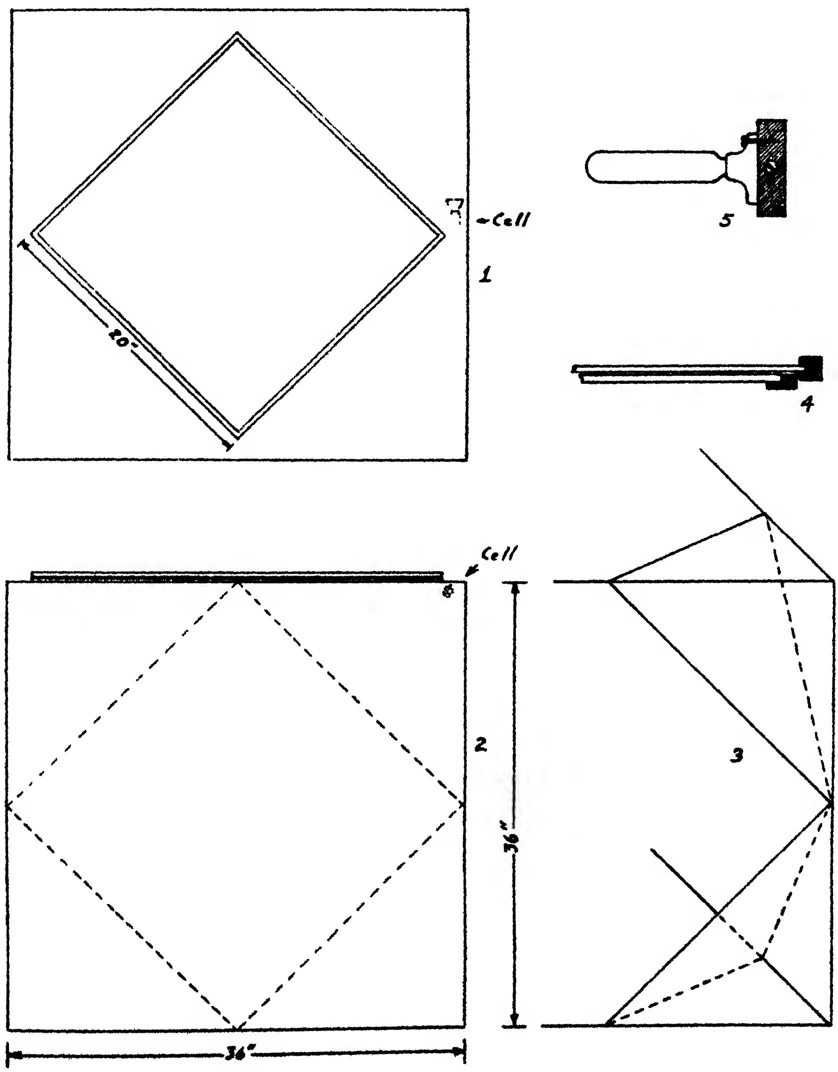

FIG. 2.

cabinet. The eight interior corners of the cabinet are all blocked off by equilateral triangular surfaces as shown in Fig. 2, 3. The inside of the cabinet is painted white or covered with white paper.

The construction of the frames for the glass plates covering the opening in the top of the cabinet is also shown in Fig. 2. One plate is cut larger than the other and both are set into frames (Fig. 2, 4) so that there will be no space between the plates when the top one is lowered. This makes it possible to press out the leaves and prevent them from rolling.

The photo-electric cell employed is a McWilliams No. 4 cell, manufactured by the Electric Bean Grader Products Company, Ithaca, Michigan. It has a dark resistance of 100,000 ohms and a light resistance of 2,000 ohms. The cell may be secured with either a candelabra screw base or a UX 201 type base. The appropriate socket is mounted on a small block of wood by means of a single screw and the block of wood is also mounted in the cabinet by using a single screw placed at right angles to that used in fastening the base. (See Fig. 2, 5.) This method of mounting the cell provides it with a universal joint which may be used to adjust the cell to the optimum working position. The socket and universal joint are mounted in the upper righthand side of the cabinet just at the junction of the points of the two equilateral triangular surfaces The mounting is made close enough to the wall of the cabinet to prevent light from the lantern falling directly upon any part of the cell.

APPARATUS FOR MEASURING RESISTANCE

The "hook-up" by which the different resistance of the cell is determined is shown in a typical "bread-board-layout" in Fig. 3. The apparatus and designations are as follows:

R_1— 2,000-ohm potentiometer (radio type).
R_2—20-ohm filament rheostat (radio type).
R_3—2,000-ohm fixed resistance.
R_4— 100-ohm fixed resistance.
R_5—Leeds and Northrup No. 4760 resistance box.
B_1— 6-volt storage battery
B_2— 22½-volt B battery
B_3— 1½-volt dry cell
U—UX 201 vacuum tube.
S—McWilliams No. 4 selenium cell
M—Milliammeter
G—Leeds and Northrup No. 2320-C galvanometer

The schematic diagram of the assembly is self explanatory. However there are a few points that should be emphasized. The polarity and voltage values for the batteries, as shown in the diagram, must

be carefully followed in connecting up the apparatus. A 45-volt B battery may be used, but it will be found that the current output will be so high that the galvanometer cannot be rapidly balanced. A milliammeter has been used with a 100-ohm resistance in series, rather than the conventional ammeter, since it makes possible a very

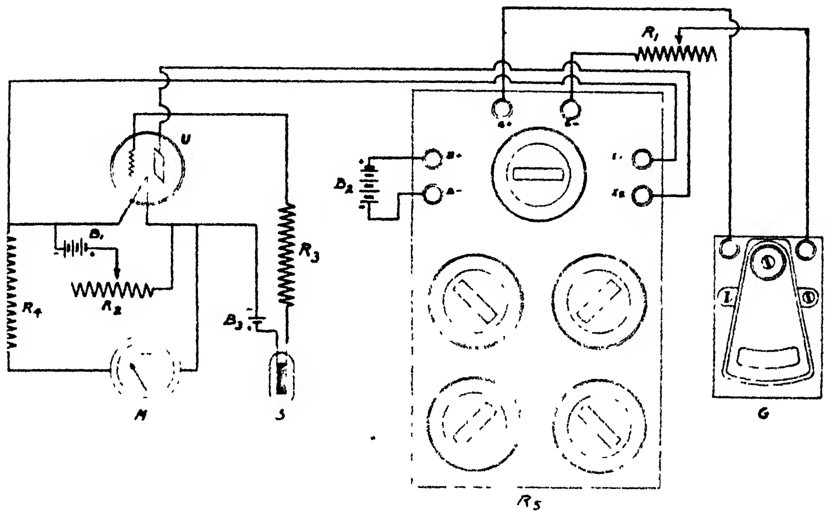

FIG. 3

fine adjustment of the filament current to the electron tube. The potentiometer, R_1, may be of larger value, since 2,000 ohms dampens the galvanometer only slightly. The entire assembly shown in Fig. 3, except the selenium cell, is mounted in a case (Fig. 1, 3), to prevent damage and possible short circuits

ADJUSTMENT AND STANDARDIZATION OF APPARATUS

After assembling the apparatus and mounting the selenium cell, it is necessary to adjust the cell and standardize the instruments. The rheostat controlling the balopticon is set so that the light is slightly dimmed. The potentiometer R_1 is opened so that its full value is used to damp the galvanometer and the filament rheostat R_2 adjusted so the milliammeter reads 40, or so the filament in the electron tube glows with moderate brightness. Before actual standardization can begin or any measurements made, it is necessary to darken the room in which the apparatus is placed. Any lights in the room other than the balopticon must be shaded so they do not effect the selenium cell.

The galvanometer key and the battery key on the resistance box R_5 are now locked down and all potentials allowed to become constant.

This may require as much as half an hour or more if the batteries are all new. When the galvanometer hand reaches and holds a steady zero reading upon adjustment of the resistance box, the potentials have become constant. A piece of cardboard of 200 to 400 square cm area is now placed on the glass plates and the dials on the resistance box adjusted until the galvanometer again reads zero with the potentiometer switched out of the line. The cardboard is moved about over the surface of the glass plate and measurements made, with necessary changes in the position of the photo-electric cell by adjustment of the universal joint, until all positions of the cardboard upon the plate give the same resistance value. It will be found that the cell will come very close to having equal values for all points upon the plate if the grid is parallel to the right-hand side of the cabinet and facing so that a perpendicular line from the center of the grid will fall at the center of the bottom of the box. If the cell is first set in this position, only slight changes will be needed to standardize the apparatus. The cabinet may be constructed with a door in the front which may be removed to adjust the cell, or the glass plates may be lifted up to reach the cell. It would be possible, of course, to construct controls whereby the cell could be adjusted from the outside of the cabinet, but since the cell is adjusted only once and permanently, these are not necessary.

MEASUREMENT OF AREA

Before actual measurement of leaf areas can be made, it is necessary to make a series of measurements of standards of known area. These standards may be cut from cardboard, and if they range in steps of 100 square cm up to the maximum capacity of the plate, a curve of resistance values may be constructed and a set of tables interpolated for every 10-ohm step of the resistance box. Measurement to closer than 10 ohms is not feasible as will be shown later. To obtain the resistance values for these standards, one is placed between the plates and the resistance reading noted, the standard is then removed and a zero, or full light, reading made. The difference between the zero reading and the value secured for the standard is the value in ohms for the area of the standard measured. The reason for using this difference value instead of actual and direct readings is because it has been found that the resistance value under full light gradually changes, becoming lower as the balopticon heats up and as the batteries gradually discharge. The difference between the zero value and the value obtained for a given area has been found to be quite constant, however, regardless of the change in the zero value. Because it takes some time for the balopticon to get hot and for the

potentials to become constant or nearly so, it is advisable to turn on the lantern and all switches for the apparatus a half hour or so before it is to be used.

ACCURACY OF THE METHOD

To determine the accuracy of the method, cardboard standards of 500, 1,000, and 2,000 square cm area were each measured 16 times. An effort was made to keep the standards so shuffled that any regular sequence of measurement would be avoided. The probable error of a single determination was found to be as follows: for the 500 square cm area, ± 15.34 square cm, or $\pm 3.3\%$; for the 1,000 square cm area, ± 11.09 square cm, or $\pm 1.1\%$; for the 2,000 square cm area, ± 16.16 square cm, or $\pm 0.8\%$. These figures indicate that the absolute error is of the same order for both small and large areas, making the percentage error smaller as the area measured is increased. The average probable error of the resistance measurement for the three areas was $\pm$ 9.99 ohms, indicating that measurements closer than 10 ohms are not sufficiently accurate to be of value.

The lack of any serious fluctuations in the sensitivity of the photo-electric cell or the amplifying powers of the electron tube is indicated by the smooth curve shown in Fig. 4. This curve has been constructed from the values obtained for a series of standards of 100 square cm intervals.

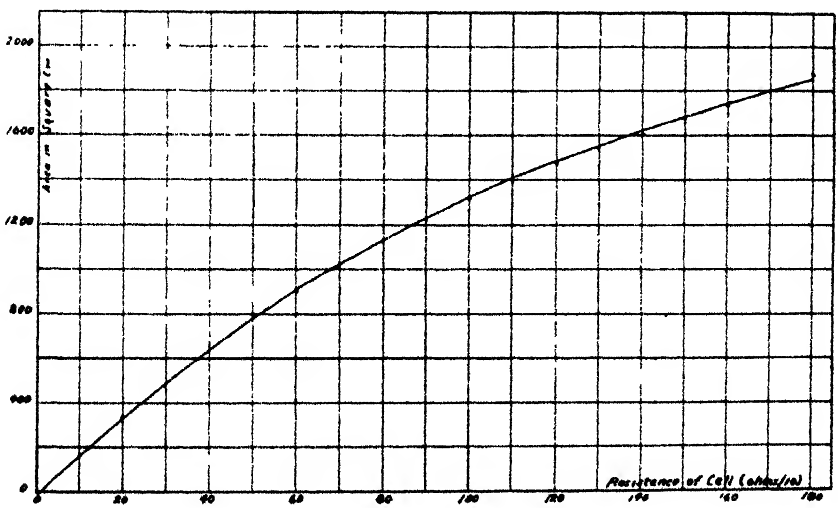

FIG. 4.—Photo-electric cell resistance-area curve.

SUMMARY

1. An apparatus has been described for making rapid measurements of leaf area by use of the selenium photo-electric cell.

2. Construction data are presented to show the assembly of this apparatus.

3. The accuracy of the apparatus is shown by a probable error for a single determination of about ±3.3% for measurements of areas of 500 square cm, ±1.1% for 1,000 square cm area, and ±0.8% for 2,000 square cm area.

APPARATUS FOR GROWING PLANTS IN SOIL UNDER MICROBIOLOGICALLY CONTROLLED CONDITIONS[1]

E. P. Deatrick[2]

The plant investigator desires many times to grow plants under microbiologically controlled conditions. Numerous pieces of apparatus have been suggested. Klein and Kisser (1)[3] published a lengthy treatise on sterile cultures and have printed sketches of 20 pieces of apparatus. Fred (2) presents a sketch of a modification of the Schulze and Schulow methods. Beaumont and Larsinos (3) have recently reported a method which is successful when using nutrient solutions.

The method herein described is for growing plants in potted soils. The two obstacles that seem to be in the way of setting up a workable apparatus of this sort are (a) a method for supplying sterile water easily, and (b) a method of covering the soil. These difficulties, it is thought, have been overcome. By the use of Livingston's auto-irrigators the supply of water may be sterilized at the same time the pot is sterilized. The rubber connection is made as shown in Fig. 1. With the irrigator reservoir raised above the level of the cones BB, water is siphoned into the system. The stopcock on the end of the pipette bulb C is closed when the water has risen to the lower end of the bulb, care being taken not to wet the cotton plug in the stem above the bulb. When the soil around the cones is well moistened, the irrigator reservoir may be lowered because water need no longer be forced through the cones, although it may be kept in the raised position to hasten the wetting up of the soil. The wetting of the surface of the soil may be observed by peering down into the broken off test tubes.

When the soil is sufficiently wet, the water bottle or flask should be set some distance below the cones. In the case of Dekalb silt loam now being used this distance is 4 feet. An uncovered pot containing 13 kg of soil was found to remain constant in weight (within 30 grams) for a period of two weeks.

Livingston, Hemmi, and Wilson (4) and Deatrick (5) describe the use of mercury manometers placed between the irrigator reservoir and the cones. In this case it is best, however, to secure correct

[1]Contribution from the Department of Agronomy, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Approved for publication as Paper No. 53 by the Dean and Director. Received for publication April 19, 1928.

[2]Associate Agronomist (Soils).

[3]Reference by number is to "Literature Cited," p. 645.

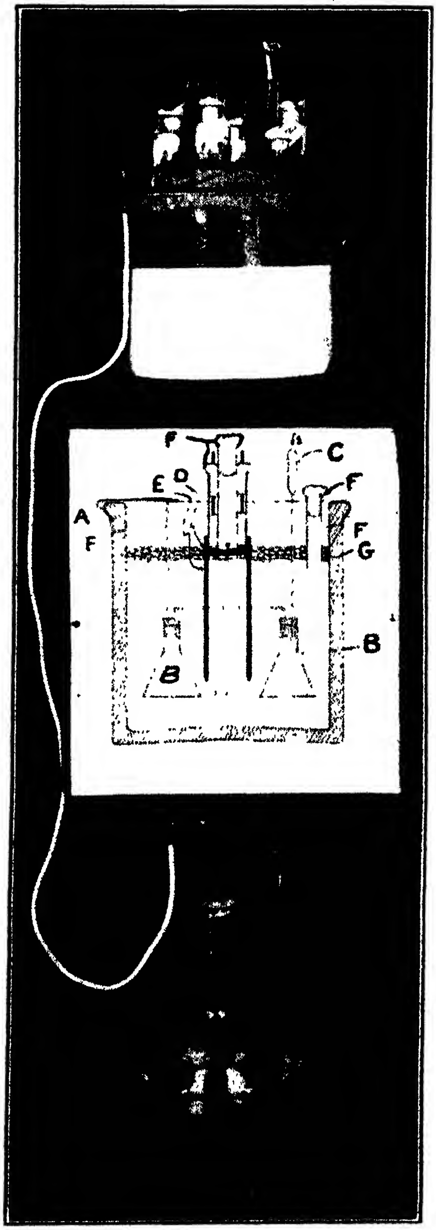

FIG. 1.—Plan of apparatus.

A, Inlet to irrigator cones. BB, Irrigator cones. C, Pipette, with cotton plug and clamp. D, Friction tape and wire, binding rods E. E, Glass rods. F, Cotton plugs. G, Gravel.

wetting by lowering the reservoir below the cones. The reservoir should be raised whenever necessary and the system filled in order to insure that any break in the capillary column be restored. If the supply of water is used up, it is not a difficult matter to replace the flask with a second one filled with sterile water.

By covering the soil with very coarse gravel it is possible to keep the cotton placed over it from becoming wet as it would, were it in contact with the soil. A paper tied over the top of the crock serves to keep the cotton in place. Details of the apparatus are shown in Fig. 1.

The cylinder arrangement for receiving the sterile seed is but an adaptation of Fred's modification (2). A cylinder of 2¼ inches in diameter and 5 inches long is fastened to three glass rods by friction tape and wire and pressed into the soil. As the plant grows the inner bottomless test tube is raised and the cotton plugs are worked around the stem. Finally, the inner tube can be pulled out entirely. The bottomless test tube at the right allows for sampling of the soil.

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THE INTRODUCTORY COURSE IN SOIL SCIENCE[1]

H. O. BUCKMAN, F. M. MILLER, AND H. L. WALSTER[2]

Individual changes in the organization of a college course or in the teaching methods applied to it are not always sound. Nevertheless it seems worth while to study at intervals the general trend of the pedagogy as recorded by a number of colleges and universities. Individual mistakes and freak developments may be minimized by numbers and certain interpretations made possible. The combined judgment and activity of many teachers of the same subject can not but be helpful in indicating, in a general way at least, what is probably suited to our present teaching situation. The data from such a survey should be of more than passing interest to our older teachers and may save the younger members of the profession some dubious experimentation.

Considerations such as these have led the Committee on Soil Teaching Methods of the American Society of Agronomy to undertake a study of the organization, teaching methods, and instructional features of the introductory course in soil science as it is taught in the United States and Canada. Questionnaires from 4 Canadian and 45 American colleges and universities form the basis for the investigation. The data are for the college year of 1927–28.

ORGANIZATION DATA

The length of term or semester at the various institutions canvassed varies from 10 to 18 weeks. At 43% of the colleges reporting the term is 18 weeks in length; at 31%, 12 weeks; and at 10% of the colleges 16 weeks.

The length of the introductory course in soil science ranges from one to three terms. In 77% of the cases the course is one term in length; in 19%, two terms; and in 4% of the cases three terms.

On the basis of weeks, the length of the introductory course varies from 10 to 36 weeks. At 43% of the institutions the course is 18 weeks in duration; at 14%, 12 weeks long; and at 12% of the institutions 24 weeks.

[1]A report of the Committee on Soil Teaching Methods of the American Society of Agronomy. A very brief report was made by this committee at the annual meeting of the Society held at Chicago in November, 1927. Received for publication April 20, 1928. Reprints of this report may be obtained from the chairman of the Committee.

[2]Professor of Soil Technology, New York State College of Agriculture, Cornell University, Ithaca, N. Y., *Chairman*; Professor of Soils and Chairman of the Department of Soils, University of Missouri, Columbia, Mo.; and Professor of Agronomy, and Chairman of the Department of Agronomy and Dean of the School of Agriculture, North Dakota Agricultural College, Fargo, N. Dak., respectively.

The comparable hours of college credit assigned to the course ranges from three to nine in total. At 32% of the institutions the credit is four hours; at 24%, five hours; at 22%, three hours; and at 14% of the colleges seven hours.

The clock-hours of instruction a week given in the general introductory course in soil science at the various institutions averages five and a half. In 33% of the cases the clock-hour instruction is six hours a week and in 31% of the courses five hours. A range from three and a half to nine clock-hours is shown by the data reported.

Prerequisite standards for the general course are difficult to generalize except as to chemistry. A knowledge of this subject is required in most cases. In fact it is difficult to see how fundamental principles can be developed adequately without chemistry as a basis. The following table sets forth the situation, the figures indicating the percentage of the institutions requiring a given subject as a prerequisite:

Introductory chemistry	89%	Physics	12%
Additional chemistry	16%	Field crops	4%
General geology	31%	Bacteriology	2%
Botany or biology	12%	No requirements (other than those of matriculation)	11%

It may be opportune to remark at this point that 90% of the institutions offer courses in soils other than the one under discussion. Such work is based on the introductory course and carries on an average 12 hours of college credit and 21 clock-hours of instruction. The credit hours range from 3 to 36 in individual cases. Such data indicate the development that has occurred in soil teaching. Whether there is an over expansion in certain cases remains to be seen.

The number of students a year registered in the general course in soil science ranges from 1 or 2 to as high as 160 when the institutions are considered separately. The average, however, is only 44 a year for the 49 schools canvassed. Obviously this latter figure is lower than the pre-war enrollment. Whether there will be an increase within the next few years is problematical.

In light of the information quoted above, the representative introductory course in soil science seems in general to cover one term, having a length of from 12 to 18 weeks. The course carries from three to five hours of college credit and the clock-hours of instruction a week range from five to six. The number of students averages 44. An introductory course in chemistry is almost always required as a prerequisite, while other courses in chemistry are sometimes asked for in addition. Geology is required in about one-third of the cases studied.

TYPES OF INSTRUCTION

The questionnaire shows clearly that the formal lecture is becoming less popular and is being replaced by a lecture-recitation type of instruction. In 35% of the courses studied formal lectures alone are used; in 49% of the cases, lecture-recitation; in 6% both types are utilized; and in 10%, neither are in vogue. Most of the professors in charge do not consider the formal lecture as an especially good method of instruction, but countenance it when the number of students is large or when the material is new and beyond the experience of the class. One instructor feels that the subject is too dry and uninteresting for successful formal lecture presentation.

Since 23% of the courses hold recitation-discussion periods from one to three times a week in lieu of lecture-recitations, the tendency is obviously towards an even more informal type of instruction than is represented by the lecture-recitation system. Assigned readings and short written quizzes are often a feature of the recitation-discussion method. Demonstrations are frequently used to lend variety and to stimulate interest.

Formal lectures when utilized generally occupy two or three hours a week. The lecture-recitation is usually held three times a week, while the more informal recitation-discussion averages twice a week for the term. Quiz sections, not a very popular type of instruction if utilization is a criterion, are generally held once or twice a week.

Laboratory work of the so-called "usual" type is a feature of the courses in introductory soil science in 76% of the cases. This laboratory usually occupies from two to three hours a week, although six hours are required in some cases. At 22% of the institutions this laboratory is supplemented by recitations or discussions. Such modifications are usually found where no regular and separate recitation or discussion hours are scheduled.

Conference periods are used in a few of the introductory courses, but apparently require more time than can be spared for this work. Such contact with the student is especially desirable when the problem method of instruction is utilized. It is hardly necessary to suggest that this type of teaching should only be done by the professor in charge or by equally experienced men.

The questionnaires gave some rather surprising but very encouraging data regarding the activities of the professors in charge of the introductory course. Apparently 70% of the teaching is done on the average by these individuals, while 11% is taken care of by others of professorial rank. Thus, only 19%, or roughly one-fifth of the instruction, is left to assistants or instructors, men supposedly of less experience and lower teaching efficiency.

SUBJECT MATTER FEATURES

Fifteen years ago the introductory course in soil science very commonly dealt only with one phase of the subject, usually soil physics; the coordinate phases being covered in later courses, generally given during successive terms. Apparently this type of subject matter organization is declining. At present 72% of the introductory courses are general in nature, that is they deal with all phases of the subject. While there is no definite information available, it seems probable that geological, physical, chemical, and biological data are brought to bear on the subject at any time and in any order best suited to develop the ideas in mind. This untrammeled use of the underlying sciences should free us from the slavishness of highly logical teaching and at the same time leave a better rounded viewpoint with the student. In other words, psychological methods of instruction seem to be gaining the ascendency in our soil science teaching.

The objectives of the introductory course as stated in the questionnaires are difficult to interpret. Some statements are well worded and specific, while others are vague and rambling. Obviously some of our professors in charge have never considered very seriously, except in a general way perhaps, what should be the aim of such a course. While the answers stress the study of soil origins and classifications, physical and chemical properties, and the like, the relationships of soil properties to crop growth seem to be the real concern. In other words, the objectives apparently are more edaphological than pedological. Morevoer, practically every course, either in itself or in subsequent work, is headed towards the development of certain systems of soil management and fertility maintenance. A "working knowledge" of the soil, as mentioned by many of the teachers, must mean an interpretation of principles into practise, an attempt to make the student think in terms of soil management and crop production.

Confirmation of this conclusion is furnished by other data from the questionnaires. Of the 49 courses studied 15% stress intensively the practical features of soil fertility and its maintenance; 61% emphasize these principles moderately; while 24% pass them with slight attention. Obviously the study of the soil is not made a mere academic exercise. The practical utilization of soil science seems to be the recognized teaching procedure in most of the courses as now given. In other words, the actual teaching emphasis, as well as that of the theoretical objectives, is edaphological.

Since the tendency seems to be towards a practical application of our soil knowledge and as the soil exists and functions normally only

in the field, it is interesting to note the amount of outside work given at the various institutions. Of the courses studied, 85% require some field study, sometimes amounting to almost all of the laboratory time each week. On the average, however, about 18% of the laboratory work is carried on in the field. On the basis of an 18-weeks course with one laboratory period a week, this amounts to only about three afternoons of field work for the term. For a 12-weeks course the same percentage of field study would mean only two afternoons.

This is not a very strong showing in light of the practical tendencies already exhibited. However, the discrepancy is easily explained. A worth while field laboratory is often difficult to organize and, if successful, always calls for skill and experience in execution. Many men do not have the time or possibly the inclination for this type of instruction. Moreover, they do not feel that they should delegate such work to their instructors or assistants. Again, the weather, especially in the North, is such as to render any great amount of field work impossible. Field instruction, therefore, sinks to a minimum in spite of the strong arguments in its favor.

The field work as given shows much variety, ranging from the investigation of weathering, soil formation, texture, structure, soil type, classification, soil profile, and sampling to studies of water and temperature relations, of erosion, tillage practises, soil mapping, experimental plats, and lysimeters. In light of their own experience, both as students and teachers, the members of the committee urge the advisability of more field instruction of this type whenever possible. Such outside contact will broaden the student's viewpoint, make the subject more tangible, and stimulate interest in and appreciation of practical problems.

One phase of the field work that is much neglected, possibly because it is rather new, is the study of the soil profile. In 45% of the courses the profile characteristics of soils receive no attention except a mere mention; 34% provide for some field examination, probably merely confirmatory of previous classroom statements; while only 21% of the courses provide for any considerable study of the various horizons of typical and important soil types.

The record regarding soil survey and classification is somewhat better. It shows that 54% of the courses provide for some instruction along these lines, usually a study of survey bulletins and maps. At 26% of the colleges reporting considerable emphasis is placed on actual mapping, the student obtaining some experience in soil identification. Whether the actual soil mapping should be left to other and later courses and the field periods be occupied in studies of a more

practical and fundamental nature is a question that the committee feels should be given serious consideration.

The indoor laboratory seems still to be confined quite exclusively to physical and chemical experiments. Of late years interest in the former phases has waned, especially as it has become apparent that exercises demonstrating obvious physical facts are a waste of time. On the other hand, studies involving acidity, lime, fertilizers, and fertility problems have increased. This, of course, is not surprising. It is surprising, however, how little of the biological phase of the soil has been carried to the laboratory of the introductory course in face of the fact that most teachers recognize the soil as a bio-collodial system. Of the courses studied 35% offer from one to five exercises of a very simple nature on soil biology. The average number of exercises is two, covering perhaps a part of a laboratory period. Nitrification, usually little more than a demonstration, is most commonly studied, although ammonification, cellulose decomposition, bacterial counts, and legume nodulation receive some attention. Here is a chance to introduce laboratory exercises that will lay the foundation for a good discussion period or, as a follow up, will substantiate a lecture-discussion period.

In discussing the weak features of the introductory course the difficulty most frequently mentioned by teachers is the lack of time. Evidently we have come to the point where teaching material is more than ample and the choice of subject matter is becoming a problem. Possibly a clearer and more specific statement of the objectives of the course would aid in such a selection. If so, an increase in teaching efficiency might be the solution of the problem rather than an extension of the time. A clearer development of ideas and principles is perhaps of greater importance than a more extended presentation of data.

Other difficulties mentioned are improper laboratory organization and equipment, lack of exercises of a biological nature, limited opportunities for field work, non-coordination of the class work and the laboratory, a text-book unsuited to the teaching set-up, untrained assistants, and students without the proper grasp of the fundamentals. None of the weaknesses mentioned are, in the minds of the com mittee members, particularly serious and should be rectified by the natural order of events.

Once the present teaching situation is clear, individual interpretation and application, tempered by a knowledge of local conditions, must be trusted to improve the introductory course in soil science, both as to organization and instruction. The committee, if it has

gone too far in offering pedagogic advice, hopes that the mistake will be laid to over-enthusiasm rather than to intentional officiousness.

AGRONOMIC AFFAIRS

FOURTEENTH ANNUAL MEETING OF THE NEW ENGLAND SECTION

The New England Section of the Society held its fourteenth annual meeting at the Hotel Bellevue, Boston, Mass., December 2 and 3, 1927. The sessions on the first day of the meeting were devoted to papers and discussions on land utilization in New England. The second day was given over to a discussion of standard recommendations of New England agronomists. Abstracts of most of the papers are held by Prof. F. S. Prince, Durham, New Hampshire, Secretary of the New England Section, space limitations in the JOURNAL precluding their publication in these pages. The program follows.

FRIDAY, DECEMBER 2

A Long Look Ahead, S. B. Haskell, Mass., Agr. Exp. Station. Discussion, W. L. Slate, Jr., Conn. Agr. Exp. Station.

State Land Utilization Programs:

Maine, G. E. Simmons, University of Maine.

Massachusetts, A. B. Beaumont, Mass. Agr. College.

Connecticut, M. F. Morgan, Conn. Agr. Exp. Station.

Rhode Island, L. A. Keegan, R. I. Agr. Exp. Station.

New Hampshire, F. S. Prince, N. H. Agr Exp. Station.

Economic Aspects of New England's Land Utilization Program, I. G. Davis, Conn. Agr. Exp. Station. Discussion, M. F. Abell, N. H. Agr. Exp. Station.

Land Utilization, O. E. Baker, U. S. Dept. of Agriculture.

The Effect of Competition from Farmers Elsewhere on a Land Utilization Program, R. W. Thatcher, Mass. Agr. College.

The Fourth Migration and Land Utilization, Phillips Bradley, Amherst College.

SATURDAY, DECEMBER 3

The Need and Opportunity for Standard Varietal Recommendations for Grain and Forage Crops, J. D. Zink, Eastern States Farmers' Exchange. Discussion, H. E. Dorsey, Conn. Agr. College.

Nutrient Needs of the Grass Crop, J. B. Abbott, National Fertilizer Assoc.

Nutrient Needs of the Potato, F. V. Owen, Maine Agr. Exp. Station.

Nutrient Needs of the Tomato, J. R. Hepler, N. H. Agr. Exp. Station. Discussion, V. A. Tiedjens, Market Garden Field Station, Waltham, Mass.

Report of the Committee on Revision of New England Standard Nine, B. L. Hartwell, R. I. Agr. Exp. Station. Discussion, R. A. Payne, N. V. Potash Export My.

The Section voted the appointment of an Advisory Committee on Varietal Recommendation for Forage and Grain Crops. The action was taken as a result of a request from one of the leading seed-handling agencies of New England. The Committee, composed

of agronomists representing each of the New England states, will serve in an advisory capacity only, its action being subject to final approval by the New England Section.

Officers for the year were elected as follows: *President*, A. B. Beaumont, Massachusetts; *Secretary*, Ford S. Prince, New Hampshire.

JOINT CONFERENCE OF NEW ENGLAND SECTION OF SOCIETY AND NEW ENGLAND FERTILIZER ASSOCIATION

At the request of the fertilizer industry, a joint meeting of the New England fertilizer interests and the New England Section of the American Society of Agronomy met in Boston, January 25 and 26, 1928. The first day separate sessions were held, while on the second day the groups met in joint session, a report of which is herewith given. The report embodies the minutes of the separate and joint sessions.

L. E. Britten, of the New England Fertilizer Association, and A. B. Beaumont, President of the New England Section of the Society, were elected joint Chairmen. J. B. Abbott and Ford S. Prince were elected secretaries.

A. B. Beaumont congratulated the body on eliminating a large number of fertilizer grades. He explained the action of the Section on January 26 and called for the report of the secretary which was read as follows:

Boston, Mass., *January 26, 1928.*

The meeting of the New England Agronomists responding to the invitation of the National Fertilizer Association met at the Hotel Bellevue, Boston, on the above date to consider matters of mutual interest with that group. The following motions were passed:

First—That we subscribe to the action of the American Association of Official Agricultural Chemists in regard to changing the term acid phosphate to superphosphate.

Second—That we register our disapproval of the use of the terms superphosphate and phosphate when used as part of the brand name as meaning a complete fertilizer.

Three—That we adopt the term nitrogen to replace the term ammonia.

Four—That we suggest to the New England Section of the National Fertilizer Association ratios offering a sufficiently wide choice to satisfy New England requirements, as follows:

N	P_2O_5	K_2O
2	14	4
2	10	8
4	6	10
4	8	8
4	10	6
4	12	4
6	8	6
8	4	8

FORD S. PRINCE, *Secretary.*

J. B. Abbot was called upon for a report of the action of the meeting of the fertilizer conference on January 26. He reported that the meeting favored keeping the term ammonia and also reported the following grades:

NH_3	P_2O_5	K_2O
2	12	4
2	10	8 (added)
3	10	4
4	8	4
4	6	10
6	3	6 (changed by vote)
5	8	7
8	6	6
6	8	6 (added)

It was moved by Mr. Brand that we dispose of the report of the Agronomy Section as read. Carried.

It was moved by Mr. Brand and seconded that we change from acid phosphate to superphosphate in this Section. Carried.

In regard to the second recommendation and after some discussion, Mr. Hazen moved that the fertilizer industry go on record as favoring the action of the agronomists not to take up any new names of this sort and that they eliminate those objectionable brand names as rapidly as they could without destroying property value and good will. Motion seconded by Mr. Davis. Carried unanimously.

Moved by Mr. Kirkham that we refer the question of changing NH_3 to N, both in buying and selling, to the Board of Directors of the National Fertilizer Association to be reported at its next annual convention with the recommendation that the change be adopted. Carried.

After discussion the following change and additions were made in the list of formulae adopted by the Fertilizer Association: 6-3-6 in place of a 5-3-5. A 2-10-8 and a 6-8-6 were added.

NEWS ITEMS

Olaf S. Aamodt, associate pathologist in the U. S. Department of Agriculture who has been stationed at University Farm, St. Paul, Minnesota, for several years, has accepted an appointment, effective November 1, with the University of Alberta at Edmonton where he will have charge of cereal breeding work. Dr. and Mrs. Aamodt will leave for Europe about the middle of June to visit Cambridge, England, Svalöf, Sweden, and points in France and Germany.

H. J. SIEMENS, who received his B. S. degree from Manitoba Agricultural College in 1925, has completed graduate work for the M. S. degree in Agronomy at the University of Minnesota and has been appointed agricultural county agent of McKenzie County, North Dakota.

I. D. ZOBELL, who joined the Agronomy Department of the Utah Experiment Station on April 1, has been placed in charge of the substation farm at Price, Utah.

D. W. PITTMAN, Extension Agronomist of the Utah Experiment Station, has organized a series of fertilizer demonstrations in typical regions of the state. The demonstration crops will include alfalfa, sugar beets, small grains, orchard fruits, strawberries, onions, and tomatoes. This type of work is new in Utah.

GEORGE STEWART, Agronomist at the Utah Experiment Station, has been notified of a grant of $1,000 from the Amalgamated Sugar Company of Ogden, Utah, for use in sugar beet breeding work. A plant breeding attack is being organized on the problem of resistance to the curly top disease of sugar beets transmitted by the sugar beet leafhopper.

P. V. CARDON has been appointed Director of the Utah Experiment Station, effective July 1, when Director William Peterson becomes Director of Extension.

GREATLY increased facilities have been provided for certain phases of plant industry work at University Farm, St. Paul, Minnesota. A new $250,000 plant industry building was recently completed. Eight greenhouse units, 18 feet by 25 feet, and four cold temperature rooms, 10 feet by 10 feet by 9½ feet in size, are nearing completion. The cold temperature rooms are equipped for temperature ranges to —50° C, each having a separate control.

WM. P. JENKS of Morristown, N. J., has provided a fund for a two-year fellowship in soil research at Rutgers University, to be known as the Wm. P. Jenks Research Fellowship. This fellowship provides for a study of soil reaction and soil composition as they relate to the growth of plants, both native and cultivated. The study will include the soils of virgin forests, reservations, lawns, and gardens. The holder of the fellowship will have the opportunity of working for an advanced degree.

C. R. RUNK, Associate Agronomist at the Delaware Experiment Station, has resigned, effective July 1, to enter industrial work.

Prof. Runk has been acting Agronomist the past year during the absence of Prof. G. L. Schuster.

ALBERT P. LARSON has been appointed Research Fellow in Farm Crops at the State College of Washington, beginning October 1, 1928. He expects to devote half time to work towards the Ph.D. degree in Plant Breeding. Mr. Larson graduated from the University of Idaho four years ago and has been pursuing graduate studies at the University of Nebraska the past two years.

F. D. FROMME has resigned his position as head of the Department of Biology, Virginia Polytechnic Institute and Plant Pathologist, Virginia Agricultural Experiment Station, to accept the position of Dean of Agriculture and Director of the Agricultural Experiment Station, West Virginia University, Morgantown, W. Va.

CORRECTION BY H. C. HARRIS

The second paragraph on page 384 of the April, 1928, issue of the JOURNAL reads as follows: "The amount of superphosphate (acid phosphate) and lime used varied to some extent and will be given in each experiment."

The tables giving these figures were omitted in condensing the material for publication, and it should have been stated that whereever lime was applied 6 grams per pot were used and that wherever superphosphate (acid phosphate) was applied, either 1.2 grams or 2.4 grams per pot were used. Of course one amount was employed throughout any given experiment.

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THE RELATION OF SOIL TYPE TO THE EXCHANGEABLE CALCIUM AND MAGNESIUM IN SOME ILLINOIS SOILS[1]

M. P. CATHERWOOD AND E. E. DETURK[2]

The problem of base exchange in soils has received considerable attention from European and American investigators during recent years. It is possible that the significance of the base exchange phenomena in soils has been overemphasized and that there may be a tendency on the part of soils investigators to attempt to explain too many soil problems by reference to the still incompletely understood base exchange phenomena. However this may be, the work of previous investigations seems to furnish evidence that the exchangeable base content of soils may be of considerable significance in the understanding and solution of many soil problems.

The present work upon the relation of exchangeable calcium and magnesium to soil type was suggested by the observation of pronounced differences in the amounts of these bases found in some untreated soils which were analyzed in a study of the influence of soil treatment upon the exchangeable base content of the soil. No attempt has yet been made to study the exchangeable sodium and potassium content of the soils reported in this paper.

Because of the large amount of work which has been reported in connection with base exchange studies of soils, most soils workers are probably familiar with the fundamental aspects of the present conception of the base exchange phenomena. Kelley and Brown, Hissink, Gedroiz, and other scientists have made notable contributions toward an understanding of base exchange in soils. It

[1]Contribution from the Division of Soil Fertility, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Experiment Station. Received for publication April 4, 1928.

[2]Graduate Assistant and Professor in Soil Fertility, respectively.

seems inadvisable to attempt an extensive review of the literature upon the subject in this paper. Suffice it to say that the exchangeable base of non-carbonate soils seems to be generally considered as that base, presumably combined with the soil colloids, which can be removed from the soil by leaching with a neutral solution of the salt of some other base. Hissink (1, 2)[3] and Kelley and Brown (4) have reported work dealing with methods of determining exchangeable bases.

There is considerable variation in the amounts of exchangeable bases found in different soils. Hissink (1) reports that the clay soils which he studied varied from 23.3 to 48.9 milligram equivalents of adsorbed bases per 100 grams of soil, while the loam soils ranged from 8.4 to 21.8 milligram equivalents in the same quantity of soil. Kelley and Brown (4) report six acid soils having from 3.9 to 8.7 and seven neutral or slightly alkaline soils as having from 6.7 to 49.9 milligram equivalents of exchangeable bases per 100 grams of soil.

As might be expected, the ratio of the amounts of the different exchangeable bases to each other varies in different soils. The average ratio (figured on the milligram equivalent basis) of the exchangeable calcium to the exchangeable magnesium in some soils reported by Hissink (1) was 6:1. This ratio for the average of the acid soils reported by Kelley and Brown (4) was approximately 2:1 and for the neutral soils 2.41:1.

In the reporting of exchangeable base data reference has sometimes been made to differences in the exchangeable base content of soils of different character, such as heavy clay soils compared to loam soils. A number of investigators are now studying the relation of exchangeable base content to soil types, but up to the present time comparatively few data have been published on this subject. Furthermore, most of the analytical results reported upon the exchangeable bases of soils have been based upon analysis of the surface soil. McCool and his associates (5, 6, 7, 8, 11) have made some chemical investigations on the entire profiles of certain soil types, and Joffe and McLean (3) have extended their studies of the base exchange phenomena to strata below the surface in the case of some soils.

The soil type is the accepted unit for the classification of soils. A study of differences between soil types should not be limited to the study of the surface stratum since types are not differentiated on the basis of the character of this stratum alone. Furthermore, any differences in the chemical nature of different soil types would be discernible by sampling the natural strata or horizons separately

[3]Reference by number is to "Literature Cited," p. 678.

rather than by taking samples to uniform, pre-determined depths, a procedure which would tend to mask such differences. For these reasons the work reported in this paper was carried out upon soils representing four well-defined types sampled by horizons.

DESCRIPTION OF SOILS

The four soil types included in this study are classified in the Illinois Soil Survey as Black Clay Loam, Brown Silt Loam, Brown-Gray Silt Loam On Tight Clay, and Light-Gray Silt Loam On Tight Clay.[4] Brief descriptions of these types follow. These descriptions were obtained at the time of sampling except in the case of Black Clay Loam, description of which is taken from Illinois Agricultural Experiment Station Bulletin 273, page 316. The type names designated by the Bureau of Soils of the United States Department of Agriculture are given in parenthesis where the correlation between the two systems of nomenclature has been established. Definite depths are assigned to the different horizons. These are the average depths and deviations of a few inches either way were found in the areas sampled.

BLACK CLAY LOAM, POORLY DRAINED PHASE (LOESSIAL CLYDE CLAY LOAM)

A_1—0 to 10 inches, black clay loam.

A_2—10 to 23 inches, drabbish black clay or clay loam.

B_1—23 to 30 or 40 inches or more, drab or strongly mottled[5] pale yellow, plastic, compact clay.

C_1—When this horizon occurs within the 40-inch section, it is usually either a strongly mottled yellow, medium-friable clay loam containing black iron concretions, or a drab clay loam splotched with yellow and containing black iron concretions.

BROWN SILT LOAM (MUSCATINE SILT LOAM)

The soil material of this type is of loessial origin. The topography is undulating to rolling, the surface drainage good, and underdrainage good to fair. The native covering consists of prairie vegetation. A profile description is as follows:

A_1—0 to 8 inches; brown, friable silt loam with some fine sand.

A_2—8 to 17 inches; darker brown friable silt loam, slightly heavy, some samples granular.

B_1—17 to 33 inches; yellowish-brown, slightly compact, clay loam to silty clay loam, ranging from friable to fairly plastic. Iron concretions frequently present.

C—33 inches to depth sampled (40 to 45 inches); yellow, mottled, silty clay loam, more friable than B. Iron concretions usually present.

[4]The capitalization of type names follows the Illinois Soil Survey System.

[5]Throughout these descriptions, mottled means mottled with gray.

BROWN-GRAY SILT LOAM ON TIGHT CLAY (PUTNAM SILT LOAM)

The areas sampled appeared to be typical for the type. The soil material is of loessial origin. The land lies flat to undulating and the natural drainage is poor, particularly in the layers below the surface. The native vegetation is prairie. This type is characterized by a sharply defined ashy gray subsurface immediately overlying a compact, plastic subsoil. A profile description follows:

A_1—0 to 8 inches; grayish-brown friable fine sandy silt loam.

A_2—8 to 16 inches; somewhat variable in the areas sampled. For the most part brownish gray friable silt loam. Yellowish cast in some cases, slightly compact in some, iron concretions in two.

B—16 to 35 inches; drabbish yellow, mottled, plastic tight clay, iron concretions; about half of samples had $CaCO_3$ concretions.

C—35 inches to depth sampled (40 to 45 inches). Pale yellow to yellow, mottled, friable silty clay loam; slightly plastic in some samples; oxidation poor to medium, iron concretions; $CaCO_3$ concretions in two.

LIGHT-GRAY SILT LOAM ON TIGHT CLAY

This is an unproductive, flat, poorly drained timber soil found in parts of southern Illinois. Like the Brown-Gray Silt Loam On Tight Clay it is characterized by a plastic, impervious subsoil overlain by an ashy gray layer which constitutes the A_2 or subsurface. It is, however, a soil of much lower productive capacity than Brown-Gray Silt Loam On Tight Clay.

A_1—0 to 6 inches; light gray friable fine sandy silt loam, often with a yellowish cast especially when moist; iron concretions often conspicuous on the surface after a rain.

A_2—6 to 17 inches; light gray to white friable silt loam, with iron concretions.

B—17 to 33 inches; pale yellow to yellow, mottled, plastic, tight clay with iron concretions.

C—33 inches to depth sampled (40 to 45 inches); yellow, mottled, silty clay loam, fairly friable but somewhat compact; iron concretions abundant.

It has been recognized by investigators in the field of soil classification that soil development consists of changes occurring in the soil material, and later in the soil, which operate in the direction of bringing it into equilibrium with its environment. The approach toward such an equilibrium (which probably can never be reached) is indicated by an increasing sharpness of definition of the soil horizons and increasing compactness or plasticity, or both, in the B horizon, a condition apparently brought about in large part by the transposition of materials into this horizon from the A above. The extent of these changes as observed in the field aids in determining

in a relative way the degree to which a given soil has approached the so-called environmental equilibrium. Shaw (10) refers to a soil which he says has apparently reached this point as a "mature soil profile." Norton and Smith (9) use the phrase "stage of development" to express essentially the same idea of relative maturity. It is obvious, as Smith[6] has pointed out, that relative maturity as used here is not necessarily related to the age of a soil in units of time, since the rate at which a soil approaches equilibrium with its environment may vary tremendously with differences in drainage conditions, topography, rainfall, and other factors. It is, indeed, quite conceivable that a given soil with very free underdrainage, moderate rainfall, and subject to surface erosion might not show any indications of horizon development within the time which would permit another soil under different conditions to develop a "mature" profile.

The authors realize that the term "relative maturity" does not rest upon a very secure footing in soil nomenclature. However, the term does serve effectively to differentiate the soil types used in this investigation, and will be used as defined in the above discussion.

The four types included in this investigation represent a wide range in degrees of development of the profile. From this point of view, the Black Clay Loam would be characterized as in early youth; Brown Silt Loam, approaching maturity; Brown-Gray Silt Loam On Tight Clay as mature; and Light-Gray Silt Loam On Tight Clay as extremely mature.

METHODS

The method used for determining exchangeable calcium and magnesium is briefly described as follows. Enough pulverized, unground, air-dry soil to be equivalent to 25 grams of water-free soil was weighed, shaken for a short time with normal potassium chloride solution, and then leached on a Buchner funnel with normal potassium chloride solution until 1 liter of filtrate was obtained. Standard chemical methods were then used for the determination of calcium and magnesium in the filtrate. No appreciable amounts of carbonate were present in any of the samples used and preliminary experiments convinced the authors that no appreciable error would result if the calcium and magnesium in the 1 liter of filtrate were considered as the exchangeable portion, since the correction due to amounts contained in the second liter was very small.

The data for total calcium and magnesium content of these soils were available when the investigation was started.

[6]SMITH, R. S. Unpublished material, University of Illinois.

TABLE 1.—*Total and exchangeable calcium and magnesium, their ratio, and the pH value of 10 samples of Black Clay Loam; A_1 horizon.*

Sample	Exchangeable Ca		Total Ca	Total Ca exchangeable	Exchangeable Mg		Total Mg	Total Mg exchangeable	Ratio M. E. exchangeable Ca to M.E. exchangeable Mg	Exchangeable Ca plus exchangeable Mg	pH value[b]
	%	M. E.[a]	%	%	%	M. E.	%	%		M. E.	
No. 1 Clyde	0.532	26.60	1.015	52.4	0.127	10.40	0.535	23.7	2.56	37.00	7.10
No. 2 Clyde	0.494	24.70	0.918	53.8	0.124	10.16	0.573	21.6	2.43	34.86	6.48
810	0.497	24.85	0.655	75.9	0.128	10.49	0.391	32.7	2.37	35.34	6.25
813	0.468	23.40	0.662	70.7	0.099	8.11	0.350	28.3	2.89	31.51	5.95
891	0.486	24.30	0.884	55.0	0.121	9.92	0.561	21.6	2.45	34.22	6.40
1004	0.512	25.60	0.761	67.3	0.153	12.54	0.580	26.4	2.04	38.14	6.40
1010	0.420	21.00	0.795	52.8	0.118	9.67	0.692	17.0	2.17	30.67	6.20
1025	0.516	25.80	0.842	61.3	0.171	14.01	0.632	27.1	1.84	39.81	6.85
1028	0.547	27.35	0.935	58.5	0.156	12.78	0.668	23.4	2.14	40.13	7.45
3664	0.494	24.70	0.862	57.3	0.113	9.62	0.562	20.1	2.57	33.96	6.90
Mean[c]	0.497	24.80	0.833	60.5	0.131	10.90	0.554	24.2	2.35	35.56	6.60
P. E. of mean	±0.0072	—	±0.0237	±1.65	±0.0045	—	±0.0222	±0.92	±0.064	±0.65	±0.093
S. D.	0.0335	—	0.1109	7.75	0.0210	—	0.104	4.31	0.298	3.03	0.438
Coefficient of variability	6.75	—	13.4	12.9	16.0	—	19.0	17.8	12.6	8.51	6.6

[a]Milligram equivalents per 100 grams of soil.

[b]Determined with the hydrogen electrode.

[c]The following formulae were used in making the statistical analysis:

(1) $\text{S. D.} = \sqrt{\frac{\Sigma D^2}{n}}.$

(2) $\text{P. E. (M)} = \pm \frac{0.6745 \times \text{S. D.}}{\sqrt{n}}.$

(3) $\text{C. V.} = \frac{100 \times \text{S. D.}}{M}.$

(4) $\text{P. E. (Difference)} = \pm\sqrt{(\text{P. E. }(M_1))^2 + (\text{P. E. }(M_2))^2}.$

TABLE 2.—*Total and exchangeable calcium and magnesium, their ratio, and the pH value of 10 samples of Brown Silt Loam; A_1 horizon.*

Sample	Exchangeable Ca		Total Ca	Total Ca exchangeable	Exchangeable Mg		Total Mg	Total Mg exchangeable	Ratio M. E. exchangeable Ca to M. E. exchangeable Mg	Exchangeable Ca plus exchangeable Mg	pH value[b]
	%	M. E.[a]	%	%	%	M. E.	%	%		M. E.	
11286	0.212	10.60	0.345	61.4	0.042	3.44	0.227	18.5	3.08	14.04	5.45
11293	0.256	12.80	0.494	51.8	0.064	5.24	0.343	18.7	2.44	18.04	5.90
11300	0.235	11.75	0.345	68.1	0.050	4.09	0.163	30.7	2.87	15.84	5.72
11307	0.194	9.70	0.352	55.1	0.041	3.36	0.195	21.0	2.89	13.06	5.65
11314	0.271	13.55	0.602	45.0	0.054	4.42	0.373	14.5	3.07	17.97	5.52
11321	0.222	11.10	0.427	52.0	0.041	3.36	0.354	11.6	3.30	13.46	5.55
11328	0.147	7.35	0.375	39.2	0.032	2.62	0.333	9.6	2.81	9.97	5.15
11335	0.170	8.50	0.446	38.1	0.036	2.95	0.310	11.6	2.88	11.45	5.50
11342	0.182	9.10	0.465	39.1	0.043	3.52	0.235	18.3	2.59	12.62	5.65
11349	0.186	9.30	0.484	38.4	0.048	3.93	0.354	13.6	2.37	13.23	5.52
Mean	0.208	10.40	0.434	48.8	0.045	3.75	0.289	16.8	2.83	13.97	5.56
P. E. of mean	±0.0079	—	±0.0163	±2.14	±0.0019	—	±0.0149	±1.24	±0.059	±0.53	±0.042
S. D.	0.0371	—	0.0762	10.05	0.0088	—	0.070	5.83	0.277	2.47	0.196
Coefficient of variability	17.8	—	17.3	20.6	19.5	—	24.1	34.7	9.8	17.6	3.5

[a]Milligram equivalents per 100 grams of soil.

[b]Determined with the hydrogen electrode.

TABLE 3.—*Total and exchangeable calcium and magnesium, their ratio, and the pH value of 10 samples of Brown-Gray Silt Loam On Tigh Clay; A_1 horizon.*

Sample	Exchangeable Ca		Total Ca	Total Ca exchangeable	Exchangeable Mg		Total Mg	Total Mg exchangeable	Ratio M. E. exchangeable Ca to M. E. exchangeable Mg	Exchangeable Ca plus exchangeable Mg	pH value[b]
	%	M. E.[a]	%	%	%	M. E.	%	%		M. E.	
11145	0.128	6.40	0.324	39.5	0.028	2.29	0.194	14.4	2.79	8.69	5.45
11152	0.116	5.80	0.419	27.7	0.025	2.04	0.204	12.3	2.84	7.84	5.10
11159	0.111	5.55	0.477	23.3	0.022	1.80	0.167	13.2	3.08	7.35	5.80
11166	0.118	5.90	0.502	23.5	0.025	2.04	0.156	16.0	2.89	7.94	5.75
11173	0.178	8.90	0.542	32.8	0.042	3.44	0.279	15.1	2.59	12.34	5.60
11180	0.167	8.35	0.560	29.8	0.032	2.62	0.232	13.8	3.19	10.97	5.60
11187	0.109	5.45	0.502	21.7	0.029	2.37	0.162	17.9	2.30	7.82	6.35
11194	0.167	8.35	0.483	34.6	0.042	3.44	0.205	20.5	2.43	11.79	6.15
11201	0.113	5.65	0.448	25.2	0.036	2.95	0.162	22.2	1.92	8.60	6.45
11208	0.146	7.30	0.471	31.0	0.032	2.62	0.174	18.4	2.79	9.92	5.75
Mean	0.135	6.75	0.470	28.9	0.031	2.60	0.195	16.4	2.68	9.33	5.80
P. E. of mean	±0.0054	—	±0.0135	±1.15	±0.0014	—	±0.0079	±0.66	±0.077	±0.36	±0.034
S. D.	0.0251	—	0.0632	5.41	0.0066	—	0.037	3.10	0.362	1.71	0.393
Coefficient of variability	18.6	—	13.4	18.7	21.3	—	19.4	18.9	13.5	18.4	6.8

[a]Milligram equivalents per 100 grams of soil.
[b]Determined with the hydrogen electrode.

Table 4.—*Total and exchangeable calcium and magnesium, their ratio, and the pH value of 10 samples of Light-Gray Silt Loam On Tight Clay; A_1 horizon.*

Sample	Exchangeable Ca		Total Ca	Total Ca exchangeable	Exchangeable Mg		Total Mg	Total Mg exchangeable	Ratio M. E. exchangeable Ca to M. E. exchangeable Mg	Exchangeable Ca plus exchangeable Mg	pH value[b]
	%	M. E.[a]	%	%	%	M. E.	%	%		M. E.	
11215	0.015	0.75	0.276	5.4	0.006	0.49	0.135	4.4	1.53	1.24	4.80
11222	0.047	2.35	0.301	15.6	0.012	0.98	0.175	6.9	2.40	3.33	5.00
11229	0.099	4.95	0.383	25.8	0.028	2.29	0.606	4.6	2.16	7.24	5.15
11236	0.011	0.55	0.265	4.2	0.009	0.74	0.130	6.9	0.74	1.29	4.65
11243	0.015	0.75	0.236	6.4	0.006	0.49	0.175	3.4	1.53	1.24	4.70
11250	0.042	2.10	0.318	13.2	0.013	1.06	0.203	6.4	1.98	3.16	4.76
11257	0.080	4.00	0.353	22.7	0.021	1.72	0.174	12.1	2.33	5.72	5.15
11264	0.041	2.10	0.313	13.1	0.010	0.82	0.206	4.9	2.56	2.92	4.90
11272	0.026	1.30	0.307	8.5	0.009	0.74	0.175	5.1	1.76	2.04	4.85
11279	0.020	1.00	0.253	7.9	0.011	0.90	0.184	6.0	1.11	1.90	4.80
Mean	0.040	1.98	0.300	12.3	0.012	1.01	0.216	6.1	1.81	3.01	4.88
P. E. of mean	±0.0058	——	±0.0088	±1.48	±0.0014	——	±0.0284	±0.49	±0.119	±0.41	±0.035
S. D.	0.0271	——	0.0412	6.96	0.0066	——	0.133	2.28	0.559	1.91	0.165
Coefficient of variability	67.7	——	13.7	5.66	52.5	——	60.0	37.5	30.9	63.7	3.4

[a]Milligram equivalents per 100 grams of soil.

[b]Determined with the hydrogen electrode.

TABLE 5.—*Summary of mean values from Tables 1, 2, 3, and 4.*

Soil type	Ratio, M. E. exchangeable Ca to M. E. exchangeable Mg	Exchangeable Ca	Exchangeable Mg	Relative amounts of exchangeable Ca	Relative amounts of exchangeable Mg	Total Ca in exchangeable form	Total Mg in exchangeable form	Non-exchangeable Ca	Non-exchangeable Mg
		%	%			%	%	%	%
Black Clay Loam	2.36	0.497 ±0.0072	0.131 ±0 0045	12.43	10.92	60.5	24.2	0.336	0.423
Brown Silt Loam	2.83	0.208 ±0.0079	0.045 ±0.0019	5.20	3.75	48.8	16.8	0.226	0.244
Brown-Gray Silt Loam On Tight Clay	2.68	0.135 ±0.0054	0.031 ±0.0014	3.38	2.58	28.9	16.4	0.335	0.164
Light-Gray Silt Loam On Tight Clay	1.81	0.040 ±0.0058	0.012 ±0.0014	1	1	12.3	6.1	0.260	0.204

PART I. INVESTIGATION OF SURFACE SOILS

The results of the analyses of the surface samples of the four types are given in detail in Tables 1 to 4, and a condensed summary is presented in Table 5.

DISCUSSION

One of the most significant facts appearing in these tables is the difference among types in the exchangeable calcium and magnesium content. The mean exchangeable calcium in Light-Gray Silt Loam On Tight Clay was found to be $0.040 \pm 0.0058\%$, in the Brown-Gray Silt Loam On Tight Clay $0.135 \pm 0.0054\%$, in the Brown Silt Loam $0.208 \pm 0.0079\%$, and in the Black Clay Loam $0.497 \pm 0.0072\%$. It will be observed that the difference in exchangeable calcium content of Light-Gray Silt Loam On Tight Clay and Brown-Clay Silt Loam On Tight Clay is 12.0 times the probable error of this difference. The differences between the Brown-Gray Silt Loam On Tight Clay and Brown Silt Loam and between Brown Silt Loam and Black Clay Loam are, respectively, 7.6 and 27.0 times the probable error of the respective differences. All of these differences are, therefore, significant by odds of a billion or more to one. More than 10 items would have been desirable for the computation of the probable errors, but it was considered that the 10 variants available would give some indication of the significance of the results.

The variations in exchangeable magnesium content are in the same direction as those for calcium. The Light-Gray Silt Loam On Tight Clay had $0.012 \pm 0.0014\%$, the Brown-Gray Silt Loam on Tight Clay had $0.031 \pm 0.0014\%$, the Brown Silt Loam had $0.045 \pm 0.0019\%$, and the Black Clay Loam $0.131 \pm 0.0045\%$ of exchangeable magnesium. The differences between the first and second types as listed above, between the second and third, and between the last two are backed by odds of over 1 billion, about 18 thousand, and over 1 billion, respectively. This leaves no doubt that the mean relative amounts of both exchangeable calcium and magnesium are definite characters of these individual soil types in so far as the samples studied are representative of those types. That is, in regard to the A horizon, these soil types appear to be set apart from each other as sharply in their exchangeable calcium and magnesium content as they are in those physical characters by which they are identified.

Figs. 1 and 2 show graphically the amounts of exchangeable and non-exchangeable calcium and magnesium in the 10 samples of each soil type. In the soil types used it is evident that the exchangeable base content decreases with an increase in maturity. The decrease in

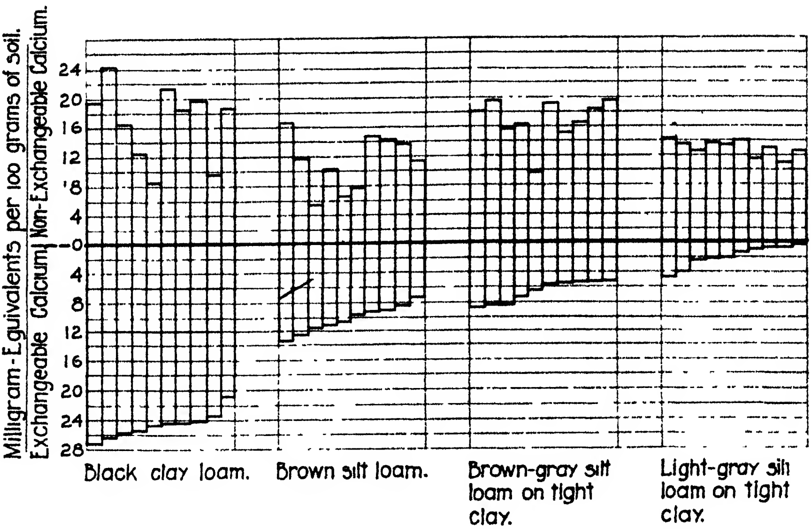

FIG. 1.—Amounts of exchangeable and non-exchangeable calcium in 10 surface samples of each of four different soil types. Arranged in order of decreasing exchangeable calcium within each type.

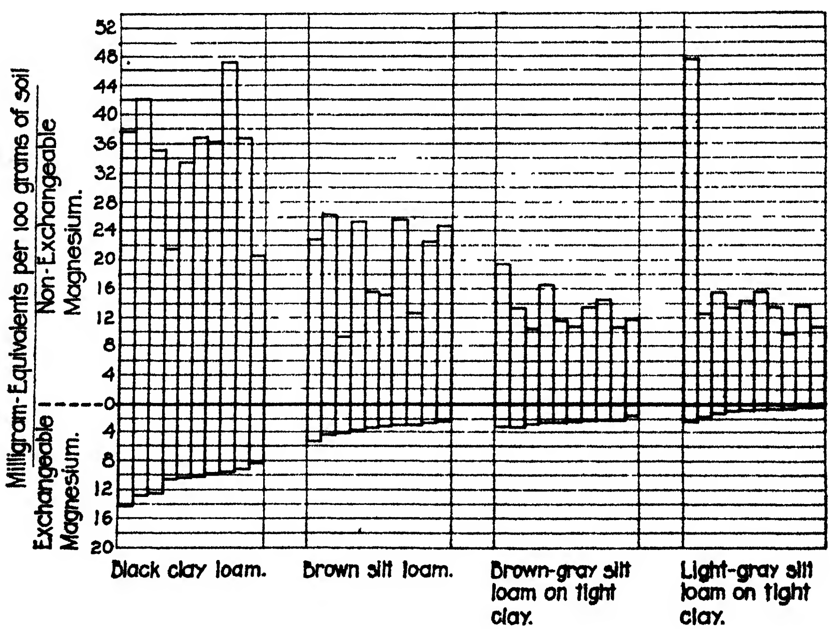

FIG. 2.—Amounts of exchangeable and non-exchangeable magnesium in 10 surface samples of each of four different soil types. Arranged in order of decreasing exchangeable magnesium within each soil type.

the exchangeable calcium and magnesium as maturity approaches is much more pronounced than the decrease in either total or non-exchangeable forms of these bases.

It will be noticed that, especially in the case of exchangeable calcium content and to a lesser extent in the case of exchangeable magnesium, there is very little overlapping of individual samples from one soil type to another. It also appears that there is a better correlation between soil type and exchangeable base content than between soil type and total base content. That is, so far as calcium and magnesium are concerned, the exchangeable base content varies inversely with the maturity of the soil type with much greater regularity than does the total base. Thus, for example, Brown-Gray Silt Loam On Tight Clay, a more mature type than Brown Silt Loam, has less exchangeable calcium than the latter type, in accord with the above observations, but the total calcium content of the two types is reversed.

Columns 4 and 5 of Table 5, in which the lowest exchangeable calcium and magnesium contents, that is those of Light-Gray Silt Loam On Tight Clay, are taken as unity, illustrate the differences in the relative amounts of these bases in the four types. Black Clay Loam has more than 10 times as much exchangeable calcium and magnesium as the most mature soil type.

While wide differences are found in exchangeable base content among soil types, the ratio of exchangeable calcium to exchangeable magnesium, ranging from 1.81 to 2.83 for the average of the 10 samples in each soil type is fairly constant. The differences in these ratios are small, although they are significant from a statistical point of view. This ratio in the neutral soils reported by Kelley and Brown (3) was 2.41 and in the acid soils 2, while in the soils reported by Hissink (1) it was 6.

In Tables 1 to 5 it is shown that there are considerable differences among soil types in the percentage of the total base present in an exchangeable form. In Black Clay Loam, Brown Silt Loam, Brown-Gray Silt Loam On Tight Clay, and Light-Gray Silt Loam On Tight Clay, respectively, the percentages of the total calcium present in an exchangeable form were found to be 60.5 ± 1.65, 48.8 ± 2.14, 28.9 ± 1.15, and 12.3 ± 1.48, and the percentages of the total magnesium in an exchangeable form were 24.2 ± 0.92, 16.8 ± 1.24, 16.4 ± 0.66, and 6.10 ± 0.49 in the same respective types. The differences between Black Clay Loam and Brown Silt Loam; between Brown Silt Loam and Brown-Gray Silt Loam On Tight Clay; and between Brown-Gray Silt Loam On Tight Clay and Light-Gray Silt Loam On

Tight Clay were, in the case of calcium, 4.30, 8.20, and 8.9 times the probable error of the differences, and in the case of magnesium, 4.8, 0.29, and 12.6 times the probable error of the respective differences. These quotients indicate significant odds in all cases except the next to last. Thus, as the maturity of the soil type increases, the percentage of the total calcium and magnesium present in an exchangeable form decreases. This fact is in line with the view that it is largely the exchangeable base which is removed from the soil by cropping and leaching and that the non-exchangeable base tends to remain in the soil in a non-exchangeable form

The relations of the exchangeable calcium to the total calcium and of the exchangeable magnesium to the total magnesium in the 10 samples of each soil type are shown graphically in Figs. 1 and 2. It will be noticed that in each soil type a considerably larger proportion of the total calcium is present in the exchangeable form than is the case with magnesium. This is in accord with the work of other investigators. It is interesting to speculate upon the significance, from the standpoint of soil development, of the figures for the non-exchangeable calcium content of the different soil types. These vary from 0.226 to 0.336%, values which appear to be rather constant when the differences in total calcium content are considered. While it seems that both exchangeable calcium and total calcium bear a direct relation to soil type, the data indicate that the correlation between soil type and *total* calcium *owes its existence to the influemce of the exchangeable portion*. The rather uniform content of non-exchangeable calcium in soils of so wide a range in stage of development would seem to indicate that the non-exchangeable calcium (in absence of carbonates) is very little influenced by the processes of weathering as compared to the decrease which takes place in the exchangeable form.

While the differences among types in non-exchangeable magnesium are greater than is the case with calcium, these differences are relatively much smaller than the differences among types in exchangeable magnesium. As has already been pointed out, the soil content of exchangeable calcium and magnesium seems to be more reliable as an indicator of the difference between types and of the maturity of the respective types than are the results of analyses for total calcium and magnesium.

So far as these samples are concerned, the pH values within each soil type are fairly constant and the mean values vary considerably from one type to another. These variations, however, are not so closely in line with variations in maturity as are the exchangeable base values.

CONCLUSIONS TO PART I

1. Consistent and significant differences were found in both exchangeable calcium and magnesium content of the surface soil of the four soil types studied.

2. As the maturity of the soil type increases the amounts of exchangeable calcium and magnesium decrease. The non-exchangeable calcium, on the other hand, is fairly constant and, while the non-exchangeable magnesium varies somewhat among the different types, the variations are small compared to those in the exchangeable portion.

3. Considerable variation was found in the percentages of total calcium and total magnesium which are present in an exchangeable form, the more mature the soil type the smaller the proportion of the total bases present in an exchangeable form.

4. In each soil type a larger percentage of the total calcium is present in an exchangeable form than is the case with magnesium.

5. The mean ratios, $\frac{\text{M. E. Exchangeable Ca}}{\text{M. E. Exchangeable Mg}}$, in the types studied are all less than 3. The variations from type to type are significant from a statistical point of view but are rather small as compared to the wide variations in the amounts of these bases present in the different types in an exchangeable form.

PART II. INVESTIGATION OF THE SOIL PROFILES

The methods used in the determinations for the soil profile study were the same as those used in the work with surface soils.

Two complete profile samples[7] of each of the four types used in the surface soil study were used in this part of the work. In selecting these samples from the groups used in the work with surface soils, one sample was taken which was found to be relatively high and another relatively low in total calcium content, except in the case of Black Clay Loam where two samples were selected in the field for this work. The descriptions of the soil types as given on pages 659 to 660 apply to these samples, since the samples of the lower horizons were collected from the same excavations as the surface samples.

DISCUSSION

The detailed data are presented in Table 6 on total and exchangeable calcium and magnesium in the four horizons of the two samples of each of the four types. Some of the relations summarized from these data are shown in Tables 7, 8, and 9. The writers realize the

[7]Each profile sample includes separate samples of each of the horizons.

TABLE 6.—*Total and exchangeable calcium and magnesium, their ratio, and the pH value of two sets of profile samples from each of four soil types*

Lab. No.	Horizon	Exchangeable Ca %	Exchangeable Ca M. E.[a]	Total Ca, %	Total Ca exchangeable, %	Exchangeable Mg %	Exchangeable Mg M. E.	Total Mg, %	Total Mg exchangeable, %	Ratio, M.E. exchangeable Ca to M.E. exchangeable Mg	Exchangeable Ca plus exchangeable Mg, M.E.	pH value[b]
Black Clay Loam (Clyde clay loam)												
Clyde No. 2	A_1	0.494	24.70	0.918	53.8	0.124	10.16	0.573	21.6	2.43	34.86	6.48
	A_2	0.448	22.40	0.914	49.0	0.119	9.75	0.596	20.0	2.29	32.15	7.33
	B	0.336	16.80	0.767	43.8	0.107	8.77	0.611	17.5	1.83	25.57	8.05
	C	0.323	16.15	0.838	38.5	0.104	8.52	0.712	14.6	1.89	24.67	8.12
Clyde No. 1	A_1	0.532	26.60	1.015	52.4	0.127	10.40	0.535	23.7	2.56	37.00	7.1
	A_2	0.462	23.10	0.885	52.2	0.128	10.49	0.657	19.5	2.20	33.59	7.55
	B	0.382	19.10	0.771	49.5	0.125	10.24	0.711	17.6	1.87	29.34	7.75
	C	0.354	17.70	0.806	43.9	0.122	10.00	0.737	16.6	1.77	27.70	7.85
Brown Silt Loam (Muscatine silt loam)												
Low Ca												
11286	A_1	0.212	10.60	0.345	61.4	0.042	3.44	0.227	18.5	3.08	14.04	5.45
11287	A_2	0.219	10.95	0.357	61.3	0.056	4.59	0.282	19.9	2.39	15.54	5.55
11288	B	0.258	12.90	0.352	73.3	0.096	7.87	0.314	30.6	1.65	20.77	5.90
11289	C	0.260	13.00	0.398	65.3	0.107	8.77	0.426	25.1	1.48	21.77	6.38
High Ca												
11314	A_1	0.271	13.55	0.602	45.0	0.054	4.42	0.373	14.5	3.06	17.97	5.52
11315	A_2	0.276	13.80	0.526	52.5	0.066	5.41	0.414	15.9	2.55	19.21	5.55
11316	B	0.346	17.30	0.522	66.3	0.126	10.32	0.628	20.1	1.68	27.62	5.98
11317	C	0.327	16.35	0.730	44.8	0.132	10.81	0.669	19.7	1.51	27.16	7.25

					Brown-Gray Silt Loam On Tight Clay (Putnam silt loam)							
Low Ca												
11145	A_1	0.128	6.40	0.324	39.5	0.028	2.30	0.194	14.4	2.78	8.70	5.45
11146	A_2	0.127	6.35	0.324	39.2	0.039	3.19	0.153	25.5	1.99	9.54	5.58
11147	B	0.226	11.30	0.368	61.4	0.104	8.52	0.494	21.1	1.33	19.82	6.15
11148	C	0.259	12.95	0.465	55.7	0.120	9.83	0.476	25.2	1.32	22.78	7.70
High Ca												
11180	A_1	0.167	8.35	0.560	29.8	0.032	2.62	0.232	13.8	3.19	10.97	5.60
11181	A_2	0.177	8.85	0.518	34.2	0.041	3.36	0.325	12.6	2.63	12.21	6.05
11182	B	0.312	15.60	0.589	53.0	0.104	8.52	0.536	19.4	1.83	24.12	6.45
11183	C	0.294	14.70	0.643	45.7	0.099	8.11	0.568	17.4	1.81	22.81	6.90
					Light-Gray Silt Loam On Tight Clay							
Low Ca												
11279	A_1	0.020	1.00	0.253	7.9	0.011	0.90	0.184	6.0	1.11	1.90	4.80
11280	A_2	0.026	1.30	0.190	13.7	0.019	1.56	0.234	8.1	0.83	2.86	4.05
11281	B	0.075	3.75	0.182	41.2	0.093	7.62	0.296	31.4	0.49	11.37	4.25
11282	C	0.096	4.80	0.319	30.1	0.093	7.62	0.349	26.6	0.63	12.42	4.55
High Ca												
11257	A_1	0.080	4.00	0.353	22.7	0.021	1.72	0.174	12.1	2.33	5.72	5.15
11258	A_2	0.149	7.45	0.440	33.9	0.053	4.34	0.289	18.3	1.72	11.79	5.75
11259	B	0.338	16.80	0.627	53.9	0.137	11.22	0.570	24.0	1.50	28.02	6.50
11260	C	0.311	15.55	0.735	42.3	0.124	10.16	0.543	22.8	1.53	25.71	7.00

[a]Milligram equivalents per 100 grams of soil.
[b]Determined with the hydrogen electrode.

desirability of examining a greater number of representatives of more types before final conclusions are drawn. They believe, however, that the relationships indicated in this part of the work will lead to further investigations for the purpose of establishing more definite criteria for the chemical characterization of soil types.

TABLE 7.—*Ratio of exchangeable calcium to exchangeable magnesium in millequivalents in different horizons of four soil types.*

Horizon	Black Clay Loam Low Ca	Black Clay Loam High Ca	Brown Silt Loam Low Ca	Brown Silt Loam High Ca	Brown-Gray Silt Loam On Tight Clay Low Ca	Brown-Gray Silt Loam On Tight Clay High Ca	Light-Gray Silt Loam On Tight Clay Low Ca	Light-Gray Silt Loam On Tight Clay High Ca	Average
A_1......	2.56	2.43	3.08	3.06	2.78	3.19	1.11	2.33	2.57
A_2......	2.20	2.29	2.39	2.55	1.99	2.63	0.83	1.72	2.08
B......	1.87	1.83	1.65	1.68	1.33	1.83	0.49	1.50	1.52
C......	1.77	1.89	1.48	1.51	1.32	1.81	0.63	1.53	1.48

TABLE 8.—*Percentage of the total calcium in exchangeable form in different horizons of four soil types.*

Horizon	Black Clay Loam Low Ca	Black Clay Loam High Ca	Brown Silt Loam Low Ca	Brown Silt Loam High Ca	Brown-Gray Silt Loam On Tight Clay Low Ca	Brown-Gray Silt Loam On Tight Clay High Ca	Light-Gray Silt Loam On Tight Clay Low Ca	Light-Gray Silt Loam On Tight Clay High Ca
A_1.....	52.4	53.8	61.4	45.0	39.5	29.8	7.9	22.7
A_2.....	52.2	49.0	61.3	52.5	39.2	34.2	13.7	33.9
B.....	49.5	43.8	73.3	66.3	61.4	53.0	41.2	53.9
C	43.9	38.5	65.3	44.8	55.7	45.7	30.1	42.3

TABLE 9.—*Percentage of the total magnesium in exchangeable form in different horizons of four soil types.*

Horizon	Black Clay Loam Low Mg	Black Clay Loam High Mg	Brown Silt Loam Low Mg	Brown Silt Loam High Mg	Brown-Gray Silt Loam On Tight Clay Low Mg	Brown-Gray Silt Loam On Tight Clay High Mg	Light-Gray Silt Loam On Tight Clay Low Mg	Light-Gray Silt Loam On Tight Clay High Mg
A_1.....	23.7	21.6	18.5	14.5	14.4	13.8	6.0	12.1
A_2.....	19.5	20.0	19.9	15.9	25.5	12.6	8.1	18.3
B.....	17.6	17.5	30.6	20.1	21.1	19.4	31.4	24.0
C......	16.6	14.6	25.1	19.7	25.2	17.4	26.6	22.8

A study of these data shows some interesting relationships. The content of exchangeable calcium plus exchangeable magnesium in milligram equivalents per 100 grams of soil for the different horizons of the eight soils is shown in Fig. 3. It is seen that when the combined exchangeable calcium and magnesium content is charted in this way the four soil types fall into place with the type considered as the least mature highest in exchangeable base content of the surface soil

and the other soil types arranged in order of increasing maturity and decreasing exchangeable calcium and magnesium. It is also noticed that in the A_1 and A_2 horizons of the two representatives of each type, the one known as the low calcium sample falls below the high calcium sample in combined exchangeable calcium and magnesium in every case. It is also seen that with increasing depth there is a tendency for the amounts of these two bases combined to converge toward a uniform value between 20 and 30 milligram equivalents per 100 grams of soil.

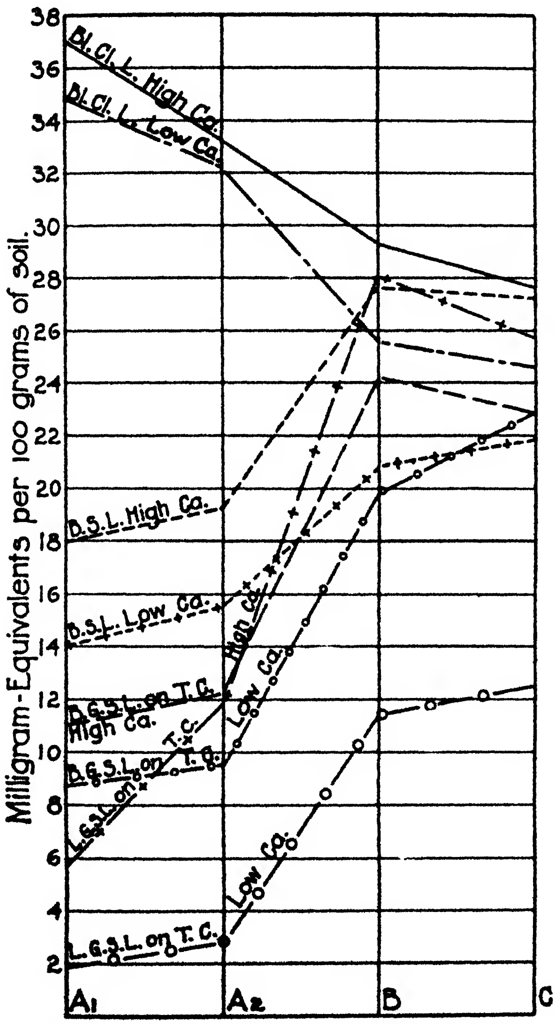

FIG. 3.—Distribution of exchangeable calcium plus exchangeable magnesium within the profiles of four soil types.

It can be seen, therefore, that, beginning with the most mature type, the relation of the exchangeable calcium and magnesium content of the two uppermost horizons to that of the deeper horizons undergoes a progressive change as we pass from the most mature to the least mature type. Thus, in the most mature type, Light-Gray Silt Loam On Tight Clay, these exchangeable bases are from four to six times as high in the B and C as in the A_1 horizon, while in the immature type, Black Clay Loam, the exchangeable

calcium and magnesium are only two-thirds as high in the B and C as in the A horizon.

This difference between types is due, in part at least, to the more thorough and complete weathering and leaching of the surface soils of the more mature types. Thus, in the surface soil of Light-Gray Silt Loam On Tight Clay, most of the exchangeable calcium and magnesium have been removed by leaching and weathering (possibly along with a considerable part of the soil colloids as well), while in the Black Clay Loam which has not been subjected to so extensive leaching most of the exchangeable calcium and magnesium originally in the surface have remained there. The decrease in exchangeable base content with an increase in depth in the case of Black Clay Loam may be due to the presence of large amounts of both organic and inorganic colloids in the surface soil of this type.

The data in Table 6 show that in all the soil types, except Black Clay Loam, both the exchangeable calcium and exchangeable magnesium increase with increasing depth. The principal increase is rather sharp at the line between the A and B horizons. The increase in the B and C as compared with the A horizons could be explained entirely on the ground that the surface soil has been subjected to greater leaching action resulting in a more complete removal of these bases. It is possible, however, that the greater leaching in the surface soil has been accompanied by the partial re-adsorption of these bases in the B and C horizons, particularly in view of their high colloid content.

Not only do the amounts of exchangeable calcium and magnesium increase with increasing depth, but the increase in exchangeable magnesium is relatively greater than that of calcium, with the result that the ratio of exchangeable calcium to exchangeable magnesium grows narrower with increasing depth (Table 7). It is possible that the removal of magnesium from the surface soil by water has been more rapid than that of calcium, and as these bases pass into the lower levels, the solution would not tend to remove further quantities of magnesium as readily as calcium. It is conceivable that these bases would be adsorbed in these lower horizons from such a solution, the magnesium at a relatively greater rate than calcium. An unpublished statistical study of total calcium and magnesium in some 5,000 Illinois soil samples shows this same relation, i. e., an increase in the proportion of magnesium to calcium in the lower strata, more pronounced in those types which are apparently more mature than in those of less maturity.

Differences in the nature or amounts of the colloids in the different horizons might also influence this ratio. The mean ratio of exchange-

able calcium to exchangeable magnesium in the A_1 horizon of the eight profiles is 2.57; in the A_2, B, and C horizons these ratios are 2.08, 1.52, and 1.48, respectively. The averaging of the values for this ratio in a given horizon of the various types would seem to be justified because of the remarkable constancy of the ratio for any one horizon even among soils which vary greatly in these constituents.

Table 8 shows the percentage of the total calcium which is present in the exchangeable form and Table 9 shows the percentage of the total magnesium present in the exchangeable form for the four horizons of the eight profiles. As would be expected, these figures vary considerably, but there seems to be a very definite tendency in the three most mature types for the percentages of these bases present in an exchangeable form to be higher in the B and C horizons than in the A_1 and A_2. This difference seems to be greatest in the most mature type and becomes progressively less as less mature soils are examined, until in the Black Clay Loam the percentage is less than that found in the A_1 and A_2 horizons. This is in line with the idea that it is the exchangeable base rather than the non-exchangeable base which is most rapidly removed from a soil, particularly the surface, during the process of weathering. Thus, the surface soils of the more mature types, having had a part of their exchangeable base leached out, have a lower percentage of the total base present in an exchangeable form. The accumulation of colloids in the deeper horizons of the more mature soils and in the A_1 and A_2 of the Black Clay Loam is undoubtedly responsible for the presence of a larger percentage of the total base in an exchangeable form in these zones.

CONCLUSIONS TO PART II

1. In the soil types studied the exchangeable calcium and magnesium taken together in the surface soil varies inversely with the apparent maturity of the soil type. Except in the Black Clay Loam, an increase in depth is associated with an increase in exchangeable calcium and magnesium

2. There is a tendency for the exchangeable calcium and magnesium content of the different soil types examined to approach a uniform value in the C horizon. This value lies between 20 and 30 milligram equivalents in 100 grams of soil.

3. The relative difference in the exchangeable calcium and exchangeable magnesium content of the surface horizon compared with the B and C horizons is greatest in the most mature soil type and becomes less as soils of less maturity are considered. Black Clay Loam is higher in these bases in the surface than in the deeper horizons.

4. The ratio of exchangeable calcium to exchangeable magnesium in any one horizon is fairly constant, even among soil types

which exhibit very great variations in their content of these constituents. This ratio tends to become narrower with an increase in depth until the C horizon is reached.

5. There is a tendency for the percentage of the total calcium and of the total magnesium present in an exchangeable form in the soils examined to increase in the B and C horizons as compared to the upper horizons, except in the case of Black Clay Loam where the reverse is true.

SUMMARY

This investigation was undertaken with a view to determining the relation of the exchangeable calcium and magnesium in soils to soil type differentiation. Four soil types were investigated. The types were described and the methods of analysis indicated.

Part I presents data on the surface samples showing the relation between exchangeable calcium and magnesium and soil type with respect to the following: (A) Relation of exchangeable calcium and magnesium to the apparent maturity of the soil. (B) Total amounts of exchangeable and non-exchangeable calcium and magnesium. (C) Ratio of exchangeable calcium to exchangeable magnesium. (D) The percentage of the total calcium and magnesium which is exchangeable. Part II gives data and conclusions resulting from analysis of all the horizons of the same types with reference to these points.

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INFLUENCE OF CROPPING SYSTEMS ON ROOT-ROTS OF TOBACCO[1]

J. P. Jones[2]

In view of the value of rotations in combating diseases and improving yields with other crops, experiments were begun at the Massachusetts Agricultural Experiment Station in 1923 to test different systems of cropping for tobacco. In the experimental scheme were included two types of rotation and five different methods of growing tobacco every year on the same land. The soil on which the experiments were conducted was a fine sandy loam typical of much of the tobacco soil of the Connecticut Valley. The plan of the experiments provided as nearly comparable conditions as possible for the different treatments.

THE CROPPING SYSTEMS

ANIMAL HUSBANDRY ROTATION

The animal husbandry rotation consisted of hay, tobacco, and corn with the tobacco always following the hay. It was not possible in this system of cropping to distinguish between the effects of hay and corn. Hence, another series of plats was laid out in which tobacco alternated with hay in one case and with corn in another. This allowed for the direct measurement of the effects of both hay and corn on the succeeding tobacco crop. The tobacco received fertilizer at the rate of 3,000 pounds per acre of a 5-4-5 mixture[3] and in addition the manure equivalent of the hay and corn grown in the rotation. The hay and corn were fertilized respectively at the rate of 400 pounds of an 8-6-6 and 800 pounds of a 3-10-6 per acre.

MONEY CROP ROTATION

In contrast with the animal husbandry rotation a rotation known as the money crop rotation was introduced in which all the crops were sold, yielding no manure with which to supplement the fertilizer applied to the tobacco. This rotation consisted of onions, tobacco, and potatoes. With tobacco following onions, this rotation did not afford the distinction between the effects of potatoes and onions on tobacco that was desired. In another series of plats tobacco alternated with onions in one instance and potatoes in another, providing for the measurement of the direct effect of each of these crops on

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[3]The fertilizer formulas used here signify ratios of NH_3, P_2O_5, and K_2O, respectively.

tobacco. At the beginning it was recognized that the success of this rotation depended upon the successful growth of each crop. The fertilizer consisted of 3,000 pounds of a 5-4-5 for tobacco, 2,500 pounds of a 5-8-7 for onions, and 2,000 pounds of a 5-8-7 for potatoes. After the experiment had been running two years it was found necessary to apply lime for onions. This was done at the rate of 1 ton per acre.

CONTINUOUS CULTURE OF TOBACCO

For comparison with the rotations, several methods of growing tobacco every year on the same land were included in the experimental plan as follows: (1) With fertilizer only, (2) with fertilizer and manure, (3) with fertilizer and timothy cover crop, (4) with fertilizer and rye cover crop, and (5) with fertilizer and redtop cover crop.

A 5-4-5 mixture of fertilizer at the rate of 3,000 pounds per acre was applied to the tobacco in each instance, and manure, where used, at the rate of 9 tons per acre.

RESULTS OF CROPPING SYSTEM EXPERIMENTS

ROTATION VERSUS CONTINUOUS CULTURE OF TOBACCO

Contrary to the results obtained with rotations for many other crops, tobacco has given the highest yield when grown in continuous culture. Manure added to the regular fertilizer gave a response of about 1% in 1924, 4% in 1925, and 7% in 1926. In 1927, when the regular fertilizer for the manure plats was reduced by 25%, the addition of manure increased the yield only 2%. None of these responses with the addition of manure have proved significant when subjected to statistical analysis, even though the treatment was replicated 8 times in an effort to minimize the probable error. The timothy cover crop has had just the opposite effect, decreasing the yield by about 13% in 1924, 16% in 1925, 9% in 1926, and 4% in 1927. The timothy cover and no-cover plats were each replicated

TABLE 1.—*Pounds per acre of cured tobacco grown in rotation compared with that grown in continuous culture.*

	1924	1925	1926	1927	Average
Continuous tobacco:					
Fertilizer only	1,316	1,275	1,655	1,523	1,442
Fertilizer and manure	1,331	1,323	1,763	1,550	1,489
Fertilizer and timothy cover crop	1,150	1,076	1,512	1,464	1,300
Fertilizer and rye cover crop[a]	——	——	1,626	1,527	——
Fertilizer and redtop cover crop[a]	——	——	1,584	1,623	——
Rotation tobacco:					
Animal husbandry rotation	1,023	929	860	1,042	963
Money crop rotation	1,103	1,357	1,426	1,433	1,330

[a]Rye and redtop were not used as cover crops until 1926, therefore no records of yields are given for 1924 and 1925.

10 times, and the difference for each year except 1927 has been found statistically significant. The results are given in Table 1.

The depressing effects on tobacco produced by the animal husbandry rotation were still more surprising and pronounced than those associated with the timothy cover crop. Approximately the same amount of plant food was furnished the tobacco as on the manure plats and more than on the no-cover plats. In spite of this the yields have fallen below those where tobacco was growing continuously without manure or cover crop, by 22% in 1924, by 27% in 1925, by 48% in 1926, and by 32% in 1927. The animal husbandry rotation has been far more detrimental than the timothy cover crop, and during the four-year period the tobacco has shown less evidence of recovery from its initial ill effects. If anything, the evidence has shown an increase in the depressing effects from year to year.

Tobacco in the money crop rotation has always yielded better than in the animal husbandry rotation. With the exception of 1925, when it yielded 6% more, it has been poorer than the tobacco in continuous culture without a cover crop, by 16% in 1924, by 14% in 1926, and by 6% in 1927. The fertilizer for the tobacco was increased from 3,000 to 3,500 pounds per acre of a 5–4–5 mixture in 1927 which may in part explain the small difference recorded.

The rye and redtop cover crop plats have been running only two years, but their performance from the standpoint of tobacco yields has been quite satisfactory. A definite decision regarding them will have to wait for a few more years' records.

From these four years' records comparing different cropping systems for tobacco it must be concluded that up to the present continuous culture is the best method of growing tobacco in the Connecticut Valley. On the other hand, the results show that the timothy cover crop so generally used may depress the yield of tobacco. Manure has shown some benefits, while the animal husbandry rotation has been a failure and so, to a much less extent, has the money crop rotation.

EFFECT OF OTHER CROPS ON TOBACCO

In another series of plats alternating tobacco every other year with onions, potatoes, corn, and hay, it is possible to estimate whether in the two rotations discussed above one or both of the crops which preceded is responsible for the poor yields of tobacco. The results are included in Table 2.

Considering the average of three years' records the tobacco yield has been decreased by corn 13% and by hay 9%. In the animal

TABLE 2.—*Pounds per acre of cured tobacco grown after different crops.*

	1925	1926	1927	Average
After onions	1,665	1,744	1,930	1,779
After potatoes	1,258	1,488	1,930	1,559
After corn	1,142	1,383	1,624	1,383
After hay	1,545	1,000	1,798	1,448
After tobacco	1,301	1,601	1,860	1,587

husbandry rotation the average decrease was 33%. This is probably greater than could be blamed on either hay or corn alone. It appears, therefore, that in this rotation the tobacco has suffered from the combined effects of both the hay and corn which preceded.

For the money crop plats tobacco following onions has exceeded that in continuous culture by 12%, while following potatoes it has been decreased two years out of three. In the money crop rotation there has been an 8% decrease during four years. Unlike the animal husbandry rotation this apparently is not due to the combined effects of the preceding onions and potatoes but chiefly to the potatoes.

METHOD OF CROPPING AND CONTROL OF BLACK AND BROWN ROOT-ROTS

In an attempt to find the explanation for some of the depressing effects noted for the different cropping systems, root examinations were made each year. The method of examining the roots consisted in collecting 10 roots at random from each plat, washing them, and recording the presence or absence of both black and brown root-rots, noting the severity of each. In 1924 a record on each plant was not kept but only an estimate as to the severity of the diseases observed. In 1925, 1926, and 1927 notes were made as to the number of plants showing diseases and the number free from them. These notes have been calculated to a percentage basis and are given in Table 3. It is true that these percentages are only rough approximations, but at the same time they afford a visible means of representing the relation of cropping to disease.

The first outstanding observation is that black root-rot does not occur extensively in any of the cropping systems. Neither was it very severe in the cases observed. The soil was very acid, pH of about 5.0 to 5.6. Anderson, Osmun, and Doran[4] have shown that in such acid soil black root-rot is never severe. When it was found necessary to add lime for onions in the money crop rotation, there was fear of increasing the black root-rot injury. The first year that

[4]ANDERSON, P. J., OSMUN, A. V., and DORAN, W. L. Soil reaction and black root-rot of tobacco. Mass. Agr. Exp. Sta. Bul. 229. 1926.

TABLE 3.—*Relation of cropping system to the occurrence of black and brown root-rots.*

	Plants	1924		1925		1926		1927		Average[b]		Average
	examined	Black	Brown	Black	Brown	Black	Brown	Black	Brown	Black	Brown	yield per acre in pounds
					%	%	%	%	%	%	%	
Continuous tobacco:												
Fertilizer only	100	trace	very mild	0	48	1	5	20	1	7	18	1,442
Fertilizer and manure	80	trace	mild	0	48	3	17	25	5	9	23	1,489
Fertilizer and timothy cover crop	100	trace	severe	0	79	6	69	9	70	5	73	1,300
Fertilizer and rye cover crop	50[a]	—	—	—	—	14	56	11	75	—	—	—
Fertilizer and redtop cover crop	50[a]	—	—	—	—	4	68	10	60	—	—	—
Rotation tobacco:												
Animal husbandry rotation	20	none	very severe	0	60	0	100	0	100	0	87	963
Money crop rotation	20	none	mild	0	60	25	50	0	67	8	59	1,330
Tobacco after:[c]												
Onions	10	—	—	0	10	20	0	0	0	7	3	—
Potatoes	10	—	—	0	60	0	50	0	0	0	37	—
Corn	10	—	—	0	80	10	40	0	0	3	40	—
Hay	10	—	—	0	33	10	100	0	0	3	44	—
Tobacco	20	—	—	0	40	0	10	0	0	0	17	—

[a]Begun in 1926. [b]Three years. [c]Begun in 1925.

tobacco followed the onions that had been limed black root-rot was considerably more prevalent than in previous years. This was thought to be the cause of the depression in the yield noted in 1926. But the yield of 1927 was similarly depressed in the absence of black root-rot. The 1 ton of lime brought the soil reaction up to about pH 5.7. This is a little too acid to expect great damage from black root-rot. It would appear that unless onions can be grown satisfactorily in this rotation at a soil reaction too acid for black root-rot to become severe the only salvation lies in the use of a black root-rot resistant strain of tobacco. So far the onions in the money crop rotation have not been a success. But when a black root-rot resistant strain 142A3X was used in 1927 after onions, it yielded 1,799 pounds per acre as contrasted with 1,426 pounds for the regular Havana seed tobacco.

Brown root-rot, on the contrary, has varied with the cropping systems. The tobacco in the animal husbandry rotation has been most severely affected. The disease has also been found to be quite severe after a timothy cover crop and after both corn and hay but slightly less after potatoes. The brown root-rot is the only unfavorable condition which has been observed for the tobacco in the animal husbandry rotation and after hay, corn, or potatoes. Therefore, the success of tobacco in rotation with these crops depends upon a better understanding of this disease. Very little brown root-rot has been observed where tobacco was grown in continuous culture without a cover crop or after onions. The superior yields obtained are believed to be due chiefly to the absence of this disease, as other conditions were comparable.

Contrary to the belief of many growers, timothy has not rid the soil of root-rots. Anderson, Osmun, and Doran have pointed out, and their conclusions are supported by the experiments reported above, that timothy has no significant effect on the prevalence of black root-rot. Instead of ridding the soil of brown root-rot timothy turned under either as a cover crop or as hay stubble has increased the severity of this disease.

For the cropping systems on which four years' records have been obtained the relation of root-rots to yield is also shown in Table 3. It should be borne in mind that these root-rot figures portray only the relative absence or presence of the disease without any reference to its severity. As a usual thing greater prevalence means greater severity.

The occurrence of black root-rot is independent of the variations in yield associated with the different cropping systems. This observation is believed to hold quite generally for acid soil conditions. If

any cropping system involves the use of sufficient lime to decrease the soil acidity above pH 5.95 black root-rot injury to the tobacco may result.[5] In cold seasons black root-rot may be harmful at soil reactions even more acid than pH 5.95. In such cases it would be due directly to the lime and indirectly to the cropping system requiring the use of lime to grow some particular crop.

The data for brown root-rot show a very definite relation between its prevalence and the yield of tobacco, the higher yields being produced where brown root-rot was relatively scarce. This disease in contrast with black root-rot was directly influenced by the crops involved in the cropping system and not by the fertilizers that were used.

SUMMARY

1. Tobacco grown every year on the same land with fertilizer only or with fertilizer and manure gave better yields than when grown in rotation with other crops, particularly corn and hay.

2. Tobacco when rotated with corn and hay showed decidedly poorer yields than when rotated with potatoes and onions.

3. Tobacco grown every year on the same land with fertilizer and a timothy cover crop was poorer than where grown similarly without a cover crop.

4. The decrease in yield caused by the timothy cover crop was not so great as that caused by hay and corn in the animal husbandry rotation

5. Observations on black root-rot of tobacco showed it to be independent of crops grown in rotation, providing the soil was quite acid, below pH 5.95.

6. Brown root-rot of tobacco was found to be associated with the cropping systems, those leaving considerable residues in the soil being most stimulative to the brown root-rot and deleterious to the tobacco.

7. Both black and brown root-rot are apparently influenced by climatic or seasonal factors because there is a very decided variation in different years with the same treatment.

[5] Morgan, M. F., and Anderson, P. J. Relation of soil reaction to black root-rot and good tobacco. Conn. Agr. Exp. Sta. Tobacco Sta. Bul. 8:47–49. 1927.

THE PROPER BINOMIAL OR VARIETAL TRINOMIAL FOR AMERICAN MAMMOTH RED CLOVER[1]

A. J. PIETERS[2]

Wherever red clover, *Trifolium pratense*, is grown two groups of cultivated forms are recognized, the early and the late flowering or, according to British usage, the double-cut and single-cut forms. In America the form corresponding to the British double-cut is known as medium, early, or June red, and that corresponding to the single-cut as mammoth red clover. The wild prototype also is known in England and in Europe, and has of late years come into some use in England. The term "medium red clover" mentioned above, while in common use in the seed trade, is an unfortunate one and has no relation to the Latin name of another species, *T. medium*. The name "medium red" could well be dropped as applied to the early red clover.

In American agronomic literature mammoth clover has often been called *T. medium*, and sometimes *T. pratense perenne*. American agronomists have frequently fallen into the error of calling mammoth clover, *T. medium*, and there are cases where men trained as botanists have not escaped this pitfall. No attempt has been made by the writer to study the numerous local floras but one case may be noted. Beal and Wheeler, (7)[3] in *Michigan Flora*, list *T. medium*, "mammoth clover," as naturalized in that state. That the true mammoth clover (*T. pratense* in the broad sense) was meant here is shown by the usage of Beal (6) in the 25th Annual Report of the Secretary of the State Board of Agriculture. On page 89 of that report he quotes Hooker's description of *T. medium* and calls it mammoth clover, but his subsequent discussion shows that the reference was to true mammoth clover and not to *T. medium*.

Garman (13), Smith (35), Bentley (8), Bailey (4), and others refer to mammoth clover as *T. medium*, while McCarthy (22) and Piper (30) use *T. pratense perenne* for mammoth clover. Bailey correctly describes *T. medium* but calls it mammoth or zigzag clover, and says: "much grown by farmers." In a later work, Bailey (5) uses *T. pratense perenne*. Kennedy (17) called attention to the error of calling mammoth clover *T. medium*, but he too considered this species the "cow grass" of England.

[1]Contribution from Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Published by permission of the Secretary of Agriculture. Received for publication April 18, 1928.

[2]Agronomist.

[3]Reference by number is to "Literature Cited," p. 700.

That the error involved is of more importance than merely the use of one name or another for the same plant is evident when it is noted that in Wolff's (45) "Aeschen Analysen" is given the composition of the ash of "*T. medium.*" One analysis is from Way and Ogston (42) and from the original report of these authors it is not possible to be certain whether they studied the real *T. medium* and called it cow grass or studied cow grass and called it *T. medium*. The other two analyses by Anderson (3), however, are clearly those of varieties of *T. pratense*, though Anderson uses the name *T. medium*. In at least one case that has come to the writer's attention chemists in the United States have quoted Wolff's analyses of *T. medium* as being that of mammoth clover. Since neither the English "cow grass" nor the true *T. medium* is the same as mammoth clover, such usage may lead to serious error.

DESCRIPTIONS OF BOTH SPECIES

The true *T. medium* is not cultivated in the United States,[4] and is but rarely found naturalized. It seems probable, therefore, that none of the American writers actually compared mammoth clover with *T medium*, but that all followed some older error. It was deemed of interest, therefore, to study the literature, especially that published in Britain, in order to determine if possible, how this error arose, and what trinomial, if any, should be applied to mammoth clover. It will be desirable before entering upon a study of the literature to describe briefly the species, *T. pratense* and *T. medium*.

Trifolium pratense in its wild state is quite variable, but is generally a short-lived perennial, with few to several stems arising from a crown. The leaflets vary from rounded through ovate, obovate or broadly oval to narrowly oblong, finely denticulate and often with a light colored crescent or triangular spot near the middle. The veins are not conspicuous, the stipules are broad, pale colored and bristle pointed with the green or purple veins often conspicuous. The stems are prostrate to ascending, glabrous, appressed hairy or rough hairy, and the roots fibrous. *Creeping rootstocks are wanting.* The flower heads are mostly sessile or short peduncled; the calyx is soft hairy.

The cultivated red clovers differ from the above mainly in having longer, more erect stems, larger leaves, and flower heads more often pedunculate. There are two groups, double and single-cut. Of the former, two cuttings can be made in one season, of the latter but one.

[4]A case of the use of *T. medium* has lately been reported from Maine where a field is said to have been on the farm of a certain family for upwards of 100 years.

The double-cut clovers are commonly early bloomers and the single-cuts late bloomers. In both groups there are several varieties. The single-cut clovers are taller than the double-cuts, bloom 10 days to two weeks later, and yield a heavier crop on the first cutting than the double-cut varieties. In leaf shape, habit, root growth, and flower head they do not differ from the double-cuts except in unimportant particulars. In the United States the mammoth is today the only representative of the single-cut clover, though in Canada the Altaswede, a selection of the Swedish late clover, has come into some use. Both double and single-cut varieties produce abundance of seed.

Trifolium medium is a long-lived perennial *with creeping rootstocks* that extend the area of the plant from 6 to 12 inches a year, and produce new plants. The leaflets are oblong to lanceolate, darker green than in *T. pratense*, the veins are prominent on the lower surface, and prolonged into delicate points at the margins. The stems are never or rarely upright. The flower heads are short peduncled and the flowers a deeper color than is commonly the case with *T. pratense*. The calyx is glabrous, except for a circle of hairs about the throat and some on the teeth. The stipules are long and narrow, tapering gradually from the base into fine points but are not awned. While the leaves of some plants of *T. pratense* may be as narrow as those of *T. medium*, the stipules are characteristic, those of *T. pratense* always broad at base and tapering abruptly into an awn, those of *T. medium* narrow at base and tapering gradually but not awned. *T. medium* produces seed very sparingly, and, as far as can be learned, always has been a shy seeder.

In England the term "cow grass" was used at one time to distinguish a variety differing from the common or double-cut red clover, but later this term became applied to all clovers, and is at present without significance. Toward the end of the 18th century, however, a late single-cut clover was introduced into the United States under the name of cow grass. Whether this variety was the ancestor of our mammoth is not known. Certainly today the English single-cut and the Scandinavian late clovers differ markedly from American mammoth. Nevertheless, the habit of growth and the agricultural use of English single-cut and of American mammoth are similar and the name of one was naturally carried over to the other. Therefore, we must look to the history of the English cow grass for an explanation of the use of the name *T. medium* for mammoth clover. A study of British agricultural literature shows that at about the time that the single-cut clover was brought to America as cow grass several writers of prominence called cow grass *T. medium*.

Early American agronomists therefore assumed that mammoth clover was identical with cow grass and, following those English writers who mistakenly called cow grass *T. medium*, also applied this name to mammoth clover. It will be shown that mammoth clover is not cow grass and that cow grass is not *T. medium*. The literature on this point is too extensive to permit of a complete review but enough will be given to show that "cow grass" as first used was a wild form of *T. pratense* differing in important particulars from the later appearing single-cut clover and still more widely from American mammoth. It will be convenient to take up the literature chronologically.

CHRONOLOGICAL REVIEW OF THE LITERATURE

Red clover was introduced into England from Flanders in 1633, according to De Candolle (12), or in 1645, the date more commonly given, and by 1652 there was some seed produced in England (Blith, 9).

The first use of the term "cow grass" so far found is that by Lisle (20), an English clergyman interested, as so many men of the cloth were, in agriculture. Lisle kept a diary, and this was edited by his son in 1757. Many of the entries are dated, however, and from this we know that "cow grass" was introduced shortly prior to 1707. Lisle says (p. 56):

"The broad clover-grass, which of late years (anno 1707) had obtained some credit, as a longer living grass than the common broad-clover, and is sown under the name of cow-grass, I find to be the common purple-trefoil, or honeysuckle trefoil, as described by Mr. Ray, vol. 1, fol. 944; distinguished from the great purple meadow-trefoil, which has always hitherto been sowed by the country farmers, and I doubt not but always will; for by experience I find the other not to yield half the burden, nor indeed, in poor ground, such as in our hill-country we commonly lay down to grass, to be a longer liver than the common sort.***"

The new clover introduced as cow grass was evidently a wild form of *T. pratense*, less productive, but said to be longer lived than the common clover.

Lisle confused Ray's (32) description of the "purple clover" or broad clover of the farmers with his description of the "greater purple meadow trefoil" which is *T. medium*, but it seems clear that the plant which Lisle called "cow grass" was some newly introduced form of *T. pratense* and not *T. medium* which is a long-lived perennial. Lisle found the cow grass to be Ray's honeysuckle trefoil which is *T. pratense*, but apparently the cow grass yielded less than the common sort introduced from Flanders, its only recommendation, evidently not sustained in Lisle's experience, being that it was longer lived.

The introduction of red clover from Flanders appears to have stimulated interest in the native wild forms, so that by 1707, some 60 or 70 years after the introduction of the cultivated red clover, new forms were being brought into culture. Gerard (14) knew of the cultivated clover as being used in the low countries and in Italy, and says that the wild red clover was eaten by "cattell and oxen."

That the wild red clover was known and appreciated by English farmers before the introduction of the cultivated form is shown by Norden (25) who states (p. 163) under a discussion of pastures, "In such a place, therefore, sow in the spring time some hay seed, especially the seed of the clover grass, or the grass honeysuckle***. But sow not the honeysuckle grass in too moist ground, for it liketh it not, therefore you must drayne the place before you sow it."

In 1771, Young (46) discussed the economics of clover growing. His work is mentioned here to point out that nowhere is there any hint that any but the common clover was known. This is true also of Mills and of many later writers. "Cow grass" is not mentioned and was evidently not common.

In 1780, Curtis (11) wrote to the Agricultural Society at Bath in reply to an inquiry about cow grass,

"There are, growing wild in this country, two species of clover, much resembling each other in size, and in the colour of their blossoms. The one is *Trifolium pratense;* the other the *Trifolium alpestre* of Linnaeus [*T. medium* Huds.]. The former is the common broad-leaved clover; the latter, the long-leaved, or creeping rooted clover; for it differs from the common broad-leaved kind, not only in having longer and narrower leaves, but also in having a root not only perennial, but creeping. Although I know with certainty that the seed of the broad-leaved clover is sold in the London shops for the true cow grass, yet I have often suspected that the different name of cow grass might originally have been given to the long-leaved sort; from its possessing some qualities superior to the other, and the seed not having been collected, the other has supplied its place."

It is evident that already the term "cow grass" had been carried over to the common broad-leaved clover, though Curtis suspects that the name may have been applied originally to *T. medium*. Why Curtis should have come to this conclusion is not clear, since there is not the least evidence in botanical literature to support such an assumption.

Martyn (21) makes clear what he believes to be cow grass. The illustration (plate 36) is clearly that of a form of *T. pratense.*

In 1791, Stokes (39) attempted to clear up the nomenclature, already confused, of cow grass and red clover. He refers to the works of Hudson and Afzelius (1) to show that the plant at that time

called *T. alpestre* was *T. medium* Huds., and definitely identifies cow grass as *T. medium*. This is the first definite identification by a professional botanist, but Stokes' memory was poor, for, in the Annals of Agriculture, 1792, he says:

"I attempted in the second edition of the Botanical Arrangement, to distinguish the latter (*T. flexuosum* Jacq.) from the *Trifolium pratense*, as follows:"*** (Then follows a description of the two ending with) "*Trifolium medium* Huds. ed. 1. Cow-grass."

It is reasonable to infer that Stokes was quoting from the second edition of Withering's (43) *Botanical Arrangement* which he assisted in preparing, but a study of this work fails to disclose the term cow grass, nor was it used in the first edition. The common names given for *T. medium* are perennial clover and marl grass. In the third edition, *T. medium* is again called perennial clover, marl grass, and also zigzag clover. The text of the fifth edition is identical with that of the third, except for a significant footnote in which a Mr. Swayne, referring to *T. medium*, says that "cattle are not fond of it till it is touched by frost," and that, pointing out to a farmer a growing plant in flower, the farmer insisted that this was not *marle* grass, but that the true marle grass of the shops was the native *T. pratense*. Marle grass, says Swayne, "was first cultivated by farmer Smith, (I believe) of Somersetshire." Note that the term "cow grass" is not used in this work but the marl grass of the shops appears to be the same plant and to have been a form of *T. pratense*.

In 1791, Afzelius (1) published an important paper clearing up the nomenclature of *T. pratense*, *T. alpestre*, and *T. medium*. While Afzelius did not use common names, the paper is of interest as showing that the plant referred to by Curtis and others about this time as *T. alpestre* was really *T. medium* of Hudson. Incidentally, Afzelius states that he has reason to think *T. medium* is not fit for cultivation.

The Rev. Charles Onley (27) writing to the Bath and West of England Society in 1786, says:

"I last year tried, instead of the common, the perennial red clover, called cow-grass (*Trifolium alpestre*) [*T. medium*] [Latin name inserted by the Secretary of the Society.] The feed from it was most luxuriant, and the butter excellent; in autumn it was turned in for wheat, of which there is on it (at present) the finest plant. If this grass be nearly equal to the common clover in produce, without danger like that to cattle in its effects, far superior in the flavor of its juices, and not an inferior bed for a crop of wheat, it merits very general attention. For my necessities it is not *sufficiently early*." (Italics in text.)

This note seems to indicate a late red clover like the present single-cut type. In the next volume is the following communication from Onley (28):

"I never saw the marle-grass you mention; but observe, you affix the same Latin name to it as you did in my letter Article XXXIV [Error, is 38] inserted in your last volume—trifolium *alpestre*, to what I there called cow-grass; and which is trifolium *purpureum pratense;* and from the trial I there mentioned to you, appears to me a most valuable species. The trifolium *alpestre* is, I apprehend, the real cow grass; though the other is, at the seed shops, sold under that name. Your society therefore, if they have acquired any quantity of the seed of the *real alpestre*, which has been thought to be *particularly rare*, will bring a very great acquisition to agriculture in one of the most essential points."

It is to be observed that the Secretary of the Society believed cow grass to be *T. alpestre* [medium], while the plant Onley called cow grass was a late form of *T. pratense*. It was also a most luxuriant grower, apparently differing in this respect from the cow grass mentioned by Lisle more than 85 years before. Onley, as well as Curtis, believed that the term "cow grass" was formerly applied to *T. medium*, but he points out that it was thought to be particularly rare; certainly, *T. medium* was not cultivated or only rarely so.

"COW GRASS" IN AMERICA

The variety mentioned by Onley was carried to America, for in 1799 Richard Parkinson (29) wrote:

"Cow-grass is a sort of clover, and so like red clover as not to be easily distinguishable when not carefully compared. The seeds of both are much alike, but there is a great difference in respect to the quality of the grasses. I have seen a much greater crop of cow-grass on the same sort of land and in the same season, than I ever did of red clover. Cow-grass will grow to a very great length, and delights in a clayey soil. I have seen it rise six feet high amongst thorns, and whins or gofs. I do not think cow-grass of a very feeding nature. It is a later plant than red clover, and sheep do not like it so well. I have seen one side of a field sown with cow-grass, the other with clover; the sheep ate the clover very bare, but left the cow-grass, as if they disliked the pasture;—at least, they certainly preferred the clover. The culture of cow-grass is the same as of red clover."

Again this form is evidently a tall-growing form of red clover and later than the common red. That this late clover was in use in more than one place in the United States is shown by a letter to the editor from an unknown Virginia subscriber (40) to the *American Farmer* under date of March 30, 1829, quoted as follows:

"Mr. Skinner: If I were to judge merely from the advertisements of our seedsmen and writers of agricultural essays, we should be naturally led to the conclusion that there was but one species of this valuable grass; it being usual with them to mention it simply under the common name of 'red clover.' Indeed it would seem that the opinion very extensively prevails, that there is but one kind. But this is an error

and ought to be corrected. We have at least two varieties in cultivation amongst us—the small early kind; and the large, late red clover.******* As far as I can learn I am inclined to believe that the *Trifolium pratense* or little red clover is the sort most generally cultivated in this country, as I find but few who appear to know anything of the large kind and most of these object to it, because they say it makes but indifferent hay, and yields but one crop in a season. But from all the experience I have of it (and I have been generally a cultivator of it for 30 years) I am inclined to believe that this is the fault, not of the grass, but of the cultivator.**** A Subscriber."

This writer does not use the name "cow grass," but his plant is quite certainly the same as that mentioned by Onley and by Parkinson, and evidently some kind of single-cut red clover. In this respect the "cow grass" of Parkinson which apparently was not uncommon in the eastern United States at the end of the 18th century resembles mammoth clover and the transition from one to the other was easy and natural.

AGRICULTURAL HANDBOOKS

In 1803, Humphreys (16) printed a compilation of agricultural information in Philadelphia, and in this he calls cow grass *T. alpestre* [medium].

Miller (23) discusses the difference between wild and cultivated red clover, and referring to Lisle's diary says: "The cow grass, however, has again been much spoken of." Miller refers to the figure in Martyn's *Flora Rustica* mentioned above to show that cow grass is a form of *T. pratense*.

In 1814, Nicholson (24) published a compilation of agricultural information in New York and in this he says:

"Red perennial clover, or cow-grass (*Trifolium medium*) is cultivated in Great Britain, in almost every kind of good upland soil, even in heavy clay lands. It is to be sowed in the spring with oats, barley, etc. It is also usual to sow it there, as well as the common red clover with the crop of flax. It rarely succeeds when sown by itself. It produces abundance of seeds, which are easily collected."

Nicholson does not give his sources but evidently followed some English writer. His statement that the cow grass "produces abundance of seeds" is in itself evidence that reference was had to a form of *T. pratense* and not to *T. medium* as the latter is notoriously a shy seeder. The same paragraph is reproduced in the edition of 1820 and may have been followed by later American writers as Nicholson's work was readily available.

HORTUS GRAMINEUS WOBURNENSIS

In 1816, Sinclair (33) gardener to the Duke of Bedford, published "Hortus Gramineus Woburnensis," the first edition of folio

size appearing in 1816. It is unique in having the text on the left and a dried specimen of the plant under discussion on the right. On page 108 is a description of *T. medium* called red perennial clover, cow grass, marl grass. Sinclair had evidently given much thought to finding a perennial form of red clover and had secured seed from various sources, but is quite specific in stating that he "could never find a perennial variety which answered to the description of *Trifolium pratense*." In his description of *T. medium*, he stresses the creeping nature of the roots. Curiously enough though he says, "To avoid any chance of mistake, therefore, I here present a specimen of the Perennial Red Clover which I have brought from a rich ancient pasture that had never been under the plough, according to the oldest recollection," the specimen on the opposite page is one of *T. pratense* and not of *T. medium*.

This statement refers to the copy of Sinclair's 1816 edition in the possession of the United States Department of Agriculture. The same error occurs in a copy at the New York Botanical Garden (letter from the Acting Director dated February 6, 1928); in one in the library of the Royal Botanic Gardens, Kew; in the copy in the British Museum (Natural History); and in that in the library of the Royal Horticultural Society. In the copy of the 1816 edition in the Linnean Society library, however, the specimen given and labeled *T. medium* appears to be as labeled (letter from the Assistant Director Royal Botanic Gardens, dated March 7, 1928). That the wrong specimen was used in this case seems probable from the fact that in the second edition, 1825, in which plates are substituted for dried specimens, the plate for *T. medium* correctly represents that species. The text of the two editions is almost identical. In the second edition Sinclair (34) drops the name "red perennial clover" but retains marl clover and cow grass as common names for *T. medium*.

In the 1825 edition Sinclair describes a perennial form of *T. pratense* and the figure (page 221) is certainly that of a form of *T. pratense*. This form, which he calls *T. pratense perenne*, he found very prevalent in the rich grazing lands in Lincolnshire. The root he describes as "slightly creeping," but clearly distinguishes it from the root of *T. medium* whose creeping roots constitute "what in arable lands is termed twitch."

LATER WRITERS

The most complete discussion of varieties of red clover published before the middle of the 19th century is that by Peter Lawson and Sons (18), Seedsmen and Nurserymen to the Highland and Agricultural Society of Scotland. Gilchrist (15) at least considers this

work worthy of greater credit than that of Sinclair. Lawson groups all the perrennial forms of *T. pratense* under *T. pratense perenne* and distinguishes four varieties. He applies the name "cow grass" to the cultivated forms.

In discussing *T. medium*, Lawson points out the scanty seed production which in itself would prevent any considerable use of the crop. The name cow grass, he says, was also sometimes applied to this species, but he considers it a weed.

In 1862, Buckman (10) called *T. medium* zigzag or true "cow grass clover." From his discussion, in which he suggests that T. *medium* "is after all but a variety of the *T. pratense*" and "is now quite merged as a farm-plant with the broad forms," it may be suspected that the author refers under *T. medium* to a late variety of *T. pratense*.

The reference to Buckman is of interest as Beal (6) in his discussion of mammoth clover refers to some of Buckman's work. Beal evidently was familiar with Buckman's writings and may have followed him in believing that cow grass was *T. medium* and that therefore mammoth clover was also *T. medium*.

In 1887, Sutton (41) discussed *T. pratense perenne* at some length and says that the farmers of Berkshire, Oxfordshire, Hampshire, and Wiltshire call this cow grass and adds that *T. medium* "has never been in commerce nor has it been grown as a crop."

In 1910, Gilchrist (15) reviewed part of the literature, some of the authors included in this review being mentioned, and concluded that the term cow grass should be applied to the late-flowering or single-cut red clover, and that this is a native selection from the wild red clover growing in English meadows.

It is clear that the first time the term "cow grass" appears in the literature (1707) it is used to refer to a wild form of *T. pratense*. Later, some writers (Curtis, Onley) "suspect" that the term originally applied to *T. medium*, though used in their time for a form of *T. pratense*. Others (Martyn, Miller) are equally clear that the true cow grass is a form of *T. pratense*. Many botanists and agricultural writers confused a form of *T. pratense* with *T. medium*. Their accounts of the use to which the plant was put show clearly that the species under discussion was *T. pratense*, even though they called it *T. medium*. The error became fixed in agricultural hand books. Meanwhile, a late variety of red clover was developed and mentioned by Onley in 1786. Popowitsch had described it even in 1765. This variety was carried to America under the name "cow grass" and if not the parent form of our mammoth, was similar to it in agricultural use. The term mammoth clover seems to have been first used

about the middle of the last century. Beal, as noted above, considered mammoth clover the same as the English cow grass and called this *T. medium*. There is reason to believe that Beal was followed by later writers and thus the error became firmly fixed in American agronomic literature.

It is of course possible that the term cow grass was anciently used for *T. medium*, though there is no indication of this in the older literature. From the fact that the meadow clover is known to have been recognized as a valuable plant in the time of Gerard and its seeding advocated at the beginning of the 17th century, while *T. medium* had the reputation of being unpalatable, it would seem most reasonable to conclude that the usage of Lisle early in the 18th century was merely a continuation of a still earlier usage. If this is correct, the term cow grass was first used for wild meadow clover, next carried over in the time of Lisle to a selection of wild red or meadow clover, and later to the late single-cut red clover which began to be cultivated about the middle of the 18th century. Since the seeds of all these forms are indistinguishable, dealers finally sold as cow grass any form of red clover, so that today, as Stapledon (36) has pointed out, the term has no meaning. Cow grass is therefore not *T. medium* but *T. pratense*.

Trifolium pratense perenne

This combination appears to have been first used by Sinclair in 1825 and a description and figure of his plant are to be found in the second edition of "Hortus Gramineus Woburnensis," p. 221–22. This was clearly a form of *T. pratense*, but the description is very general, the differences emphasized being the slightly creeping root, deeper color, greater hairiness, longer, more slender, and less upright stems, and permanence. Nothing is said about date of maturity so it is not possible to be certain whether Sinclair's plant was like the tall, late form previously described by Onley, Parkinson, and others. It should be distinctly noted that Sinclair did not call his form "cow grass."

In 1836, Lawson used the combination as a group designation for all perennial varieties. Two classes are, however, included in this group, one the "native perennial red clover" is evidently a wild form, while the others, among them "cow grass," are cultivated forms, differing one from the other in height, habit, and earliness but all more like cultivated red clover than like the "native perennial" and having but one character in common—alleged permanency. Lawson based the group *T. pratense perenne* wholly on permanency, disregarding morphological characters and flowering habit.

The French and the German varieties classed under *T. pratense perenne* are both described as of a dwarf and spreading habit—quite different from the modern late-flowering clover. The form to which Lawson gives the name cow grass is the only one of the group distinguished by being late blooming. This is said to resemble the common biennial except for more woolly leaves, and later bloom. It is probably the same form as that mentioned by Parkinson in America and from it the American mammoth may have been derived.

In 1883, Stebler and Schroeter (37) published the first edition of "Die Besten Futterpflanzen" and on p. 73 describe the wild meadow clover *T. pratense "pratarum"* Alefeld and add, "Older and probably better chosen is the name *T. pratense perenne* Hort." In this connection it may be noted that in McAlpine's translation "Hort." is written "Host" and this is also the case in a French translation of the second edition. In the fourth edition Stebler and Volkart (38) credit the combination to Sinclair.

The combination *T. pratense pratarum* Alefeld is thus definitely connected with Sinclair's description of *T. pratense perenne.* But Alefeld (2) says of *T. pratense pratarum* that it is the commonest wild form and Stebler and Schroeter say, "permanent meadow clover, in Switzerland called natural clover, matting clover (Mattenklee), in Germany Bullenklee, in England, cow grass. This form remains *lower* (italics mine) than the cultivated." In a later edition of "Die Besten Futterpflanzen," Stebler and Volkart (38) place *T. pratense perenne* among the cultivated, not among the wild forms, and include under this group designation Mattenklee, cow grass, Scandinavian late, and American mammoth. This usage scarcely commends itself to the present writer, however, since Mattenklee is an early double-cut variety, and Scandinavian late and American mammoth are late single-cut varieties. Nothing is said about date of blooming of *T. pratense perenne.* This is a very important character in late English clover and in American mammoth. In one American test with Swiss Mattenklee, the plants proved to be as early as common red clover.

Nowacki (26) also identified *T. pratense perenne* with Mattenklee and "cow grass" and says, "This wild meadow or matting clover is of slower growth and less luxuriant but is more winter hardy, less particular about soil, and lasts longer."

It will be noted that while Sinclair describes his *T. pratense perenne* as having longer and more slender stems both Stebler and Volkart and Nowacki say that it is of lower growth.

Raum (31), in 1915, refers the wild meadow clover to *T. pratense perenne* and says:

"The genuine meadow clover is readily distinguishable from the cultivated. It shows the character of a primitive stock, with great variability. Some plants have few leaves and almost nothing but stems, others are leafy. The low almost procumbent habit is characteristic. Even the flower stalks have knee-like shape and are quite devoid of leaves. They bloom freely even in the first year and the flower stalks grow rapidly after cutting. The two varieties *Trifolium pratense perenne* and *Trifolium pratense sativum* grade into one another. The Swiss 'Mattenklee' is thought to be a strain lately split off from the original species and characterized by the many flower stalks in proportion to the leaf mass and by its early bloom. It bloomed in July of the season of seeding."

Sinclair is indefinite in his description of *T. pratense perenne*, but it was clearly a wild form of *T. pratense*. Stebler and Schroeter and Nowacki describe it as lower growing than the common red clover and the former definitely link it up with Alefeld's "*pratarum*." Raum uses the term for wild meadow clover. The Swiss Mattenklee, which is given by all these German writers as typical, is a relatively low-growing clover, but upright, early to bloom, and makes a prompt recovery after bloom.

The American mammoth, on the contrary, is late, tall, coarse, and does not make two crops of stems in a season. Neither is it conspicuous for durability. The stems are not solid, in fact, the proportion of solid and of hollow stems in any stand is about the same as in the common red. Nor does mammoth clover ever have an even slightly creeping root.

In regard to the use of the combination *T. pratense perenne* for cow grass it may be remarked that the original description of Sinclair does not agree with that of the modern late-flowering single-cut red clover unless it be in respect of permanence, about which the present writer is not able to judge. Under American conditions today the late-flowering single-cut English clover is no more permanent than the double-cut, but it is realized that conditions here are very different from those in England. The descriptions given for *T. pratense perenne* by Stebler and Schroeter, by Nowacki, and by Raum all point to a low-growing and early-flowering plant. The description in Stebler and Schroeter and especially the reference to Alefeld's "*pratarum*" and to the Swiss Mattenklee point to a very different plant from the late-flowering single-cut red clover or the American mammoth. Sutton uses *T. pratense perenne* for what is clearly the late-flowering single-cut clover. He refers to its flowering 10 days later than common red, to its rarely giving a second cutting, and to its greater height, all characters which distinguish the late single-cut forms from the early double-cut clovers. This description is, how-

ever, not in accord with that of Lawson, Stebler and Schroeter. Raum, and others.

WITTE'S GROUPING THE MOST SATISFACTORY

In America one variety of early clover, June red, is recognized and, except for the limited culture of Altaswede, but one variety of late clover—the mammoth. In Europe, however, many varieties have been noted, though most of these appear to be but little more than regional strains. They all fall naturally into two groups, early and late, and Witte (44) has used this character as a basis for classification. He grouped the red clovers into wild red, *T. pratense* var. *spontaneum* Willk (= *pratorum*-Alef.), and cultivated red, *T. pratense* var. *sativum* Schreb. Under the wild reds he places the Swiss Mattenklee and the "genuine English cow grass." The cultivated forms are further divided into early, *T. pratense* var. *praecox*, and late, *T. pratense serotinum*. The late clovers, he adds, are known in England as "single-cut clovers."

Lindhard (19), followed substantially the same classification.

The present writer questions the desirability of applying a Latin trinomial to such a form as American mammoth clover, where the botanical distinctions are not pronounced and constant. In fact, earlier and later strains of mammoth clover have been noted and could be selected and fixed. It would seem sufficient in agronomic literature to refer to the variety as *T. pratense*, mammoth, or in anv botanical classification to group it with other single-cut clovers under the trinomial *T. pratense serotinum*.

SUMMARY AND CONCLUSIONS

While the incompleteness and sometimes inaccuracy of many of the descriptions by the older agricultural writers render it impossible to arrive at positive conclusions in regard to the plant originally called "cow grass," the following summary and conclusions will make clear the grouping of varieties of red clover and what are believed to be the facts concerning the relations between the terms "cow grass," "mammoth red clover," and "*Trifolium medium*."

1. *Trifolium pratense*, red clover, and *T. medium*, zigzag clover, are two somewhat similar but readily distinguishable species. They are most readily separated by the stipules, calyx, and rootstock. The stipule in *T. pratense* is broad at base and awned, that of *T. medium* narrow at base and tapering to a point but not awned. The calyx of *T. pratense* is hairy on the outside, that of *T. medium* glabrous. *T. pratense* has no rootstock, while *T. medium* has a strong creeping rootstock.

2. The cultivated red clovers belong to two groups, early or double-cut and late or single-cut. There are in Great Britain and in Europe several forms or varieties in each group. The name "cow grass" has been more or less loosely applied to early and late varieties. In America there is in the main one double-cut and one single-cut variety. The latter is known as mammoth red clover.

3. The name "cow grass" was first used in 1707 for a selection from wild red clover and during the following hundred years more than one such selection appeared in British agriculture. The seed, however, was difficult to get and the name was soon carried over to the common red clover which was sold in the seed shops as "cow grass."

4. About the middle of the 18th century a late, single-cut red clover, the origin of which is not known, appeared in European agriculture and this was referred to in England as cow grass. Later this was carried over to America and may have been the ancestral stock from which our mammoth clover was derived.

5. Many British writers mistakenly referred the "cow grass" to *T. medium*, and American agronomists, assuming that "cow grass" was the same as mammoth red clover, naturally followed the British error and applied the name *T. medium* to mammoth red clover.

6. The name *T. pratense perenne* was applied by Sinclair to a selection of wild red clover but he did not call this cow grass. This trinomial was later used by various writers as a group designation for various selections from wild red clover, including, in some cases "English cow grass."

7. These selections from wild red clover all differ markedly from the modern English single-cut and from American mammoth and the trinomial *T. pratense perenne* can not properly be applied to mammoth red clover.

8. A correct Latin trinomial for mammoth red clover does not exist and there is no reason for the use of such a trinomial in agronomic literature. Botanically, mammoth clover may be grouped with other late-flowering, single-cut forms under *T. pratense serotinum*.

It is hoped that the present discussion will put an end to the use of the name *T. medium* for mammoth clover.

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VARIABILITY IN STAPLE LENGTH OF SOME COMMERCIAL VARIETIES OF COTTON[1]

H. E. REA[2]

INTRODUCTION

The value of lint cotton is largely contingent upon certain of its marketable qualities. The length and uniformity of staple probably influence the marketable quality of lint cotton more than any other characteristic, with the possible exception of the grade. More emphasis is now being placed upon uniformity of length of staple than ever before, since uniformity is one of the most important characteristics contributing to the ultimate spinning value of the lint.

The object of this study was to determine the uniformity in the length of staple characteristic of a number of the important commercial varieties commonly grown in Texas. The experiment stations have helped the individual farmer to select intelligently the particular variety he should plant by testing some of the more promising strains and varieties on a comparable basis. The importance of staple length has been emphasized in these tests. However, length of staple determinations have usually been based upon a single massed sample of lint from each variety. These observations on the length of lint have been made by licensed cotton classers and reported along with the general results of the variety test. Data bearing upon the relative uniformity of length of staple for the different varieties have not been available as a basis for improvement of this character.

METHODS USED

In 1925 and 1926, samples of lint were taken from approximately 50 individual stalks within each of 16 varieties. These stalks were harvested from plats grown under uniform conditions and were taken consecutively as they stood in the row in order to secure a representative sample. The length of staple measurements for 1925 were made on ginned samples of lint, while measurements for 1926 were made with the lint still on the seed. Since the 1925 samples were ginned on a roller gin and "gin cutting" practically eliminated, the measurements for each of the two years were considered to be the true length of the fiber. Thus, the records on the individual stalks within each variety furnished interesting data from which the variation in length of staple may be studied.

[1]Contribution from Substation No. 5, Texas Agricultural Experiment Station, Temple, Texas. Received for publication April 20, 1928.

[2]Agronomist.

The data for 1925 were obtained from stalks grown during a very dry year on Abilene clay upland soil, while the data for 1926 were obtained from stalks grown on Trinity clay bottom land soil during a favorable season of high rainfall. The 1925 results should give a very good indication of the variability in staple length that may be expected under a very dry and unfavorable condition, while the 1926 results should indicate the performance to be expected under very favorable conditions. The annual rainfall and its distribution for each of these seasons in comparison with the normal is given in Table 1.

TABLE 1.—*Distribution of rainfall by months, Temple, Texas.*

	1925	1926	14-year mean
January	1.38	6.23	2.65
February	0.17	0.18	1.94
March	0.00	6.48	2.35
April	1.99	5.92	5.02
May	2.60	2.14	3.76
June	0.31	2.65	2.27
July	0.51	1.40	1.27
August	1.89	1.31	2.94
September	3.77	2.05	4.32
October	5.88	7.26	3.39
November	3.67	1.78	3.38
December	0.50	3.71	3.03
Total	22.67	41.11	36.32

EXPERIMENTAL RESULTS

The frequency distribution, the mean length, and the coefficient of variation of staple for the various varieties of cotton grown in 1925 are presented in Table 2. The range in length of staple of all varieties for this year was from twelve-sixteenths to twenty-sixteenths inch. The most frequently occurring length of staple was fifteen-sixteenths of an inch, and the distribution around the mode conformed somewhat closely to a normal frequency distribution. The modal lengths of lint of the 16 varieties fell into four general classes. The mode of Kasch, Qualla, Anton, Rowden, and New Boykin is found in the fourteen-sixteenths inch class; Harper, Cliett's Superior, Mebane, Belton, Lone Star, Truitt, and Acala in the fifteen-sixteenths inch class; Lankart and Sunshine in the sixteen-sixteenths inch class; and Durango and Snowflake in the eighteen-sixteenths inch class.

Table 3 presents the frequency distribution, the mean length, and the coefficient of variation of staple for the varieties grown in 1926. The range of the length of staple for this season was from ten sixteenths to twenty-three sixteenths inch. The modal length of all

TABLE 2.—*Frequency distribution, mean, and coefficient of variation of staple length in 1925 cotton varieties at Temple, Texas.*

Variety	Class centers in sixteenths inch—Staple length										Mean	Coefficient of variation
	12	13	14	15	16	17	18	19	20	Total		
Durango	—	—	—	—	3	13	22	7	5	50	17.96±.10	5.67±.38
Harper	1	2	16	22	8	—	—	—	—	49	14.69±.08	5.87±.41
Lankart	1	—	1	11	21	8	1	—	—	43	15.84±.10	6.08±.44
Cliett's Superior	—	3	14	17	15	1	—	—	—	50	14.94±.09	6.34±.43
Kasch	7	16	21	6	1	—	—	—	—	51	13.57±.09	6.88±.46
Qualla	2	3	9	9	1	—	—	—	—	24	14.17±.14	6.96±.68
Mebane	1	9	15	17	8	—	—	—	—	50	14.44±.10	7.08±.48
Belton	4	1	9	19	17	—	—	—	—	50	14.88±.11	7.68±.52
Anton	4	9	13	8	2	1	—	—	—	37	13.95±.13	8.32±.66
Lone Star	5	6	12	22	3	2	—	—	—	50	14.36±.11	8.33±.57
Truitt	4	8	16	17	6	2	—	—	—	53	14.36±.11	8.35±.55
Rowden	1	2	16	10	15	3	3	—	—	50	15.14±.13	8.66±.55
Acala	3	4	7	17	16	3	2	—	—	52	15.08±.13	9.00±.60
Sunshine	4	10	10	12	13	1	—	—	—	50	14.46±.13	9.20±.63
Snowflake	—	—	2	4	8	9	10	9	8	50	17.60±.12	9.58±.65
New Boykin	5	9	16	8	8	4	—	—	—	50	14.34±.13	9.82±.67
Total	42	82	177	199	145	47	38	16	13	759		
Mean											14.99±.22	7.74±.23

TABLE 3.—*Frequency distribution, mean, and coefficient of variation of staple length in 1926 cotton varieties, Temple, Texas.*

Variety	Class centers in sixteenths inch—Staple length																Coefficient of
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total	Mean	variation
Harper	—	—	—	5	18	12	1	—	—	—	—	—	—	—	36	14.25±.08	5.06±.40
Lankart	—	—	—	—	3	15	16	2	1	—	—	—	—	—	37	15.54±.09	5.31±.42
Mebane	—	—	—	—	1	5	12	3	3	—	—	—	—	—	24	16.08±.13	6.03±.59
Rowden	—	—	—	1	8	15	11	1	1	—	—	—	—	—	37	15.16±.11	6.42±.51
Snowflake	—	—	—	—	—	—	—	1	3	5	19	6	6	2	42	20.24±.14	6.45±.48
Belton	—	—	—	1	12	12	9	3	—	—	—	—	—	—	37	15.03±.11	6.65±.52
Cliett's Superior	—	—	—	3	8	3	9	—	—	—	—	—	—	—	23	14.78±.16	7.45±.75
Qualla	—	—	—	1	9	8	10	3	1	—	—	—	—	—	32	15.25±.14	7.51±.59
Anton	—	—	2	—	12	12	5	1	1	—	—	—	—	—	33	14.76±.14	8.00±.67
New Boykin	—	—	3	4	8	16	3	2	—	—	—	—	—	—	36	14.50±.14	8.37±.67
Lone Star	—	1	—	3	6	13	14	3	1	—	—	—	—	—	41	15.17±.14	8.48±.64
Truitt	1	—	1	1	9	12	8	—	—	—	—	—	—	—	32	14.66±.15	8.63±.73
Kasch	—	—	2	1	14	9	9	1	—	1	—	—	—	—	37	14.81±.15	8.86±.70
Acala	1	—	—	2	5	11	12	7	—	—	-	—	—	—	38	15.32±.15	9.12±.71
Sunshine	—	—	1	3	3	11	8	11	3	—	—	—	—	—	40	15.68±.16	9.28±.71
Westex[a]	—	1	4	6	7	5	2	—	—	—	—	—	—	—	25	13.68±.17	9.41±.91
Durango	—	—	1	1	3	5	8	6	9	4	2	—	—	—	39	16.67±.20	11.15±.86
Total	2	2	14	32	126	164	137	44	23	10	21	6	6	2	589		
Mean																15.39±.24	7.78±.27[b]

[a]The Westex variety is not discussed in the text of this article because records are available for only one year.
[b]Westex eliminated from this mean for purpose of computing indices in Table 4.

varieties was fifteen sixteenths inch, which was the same as that found in 1925. The modal length of the several varieties was found in the following classes: Harper, Kasch, and Westex, fourteen-sixteenths-inch class; Cliett's Superior, Rowden, Belton, Anton, New Boykin, Truitt, and Sunshine, fifteen-sixteenths-inch class; Lankart, Mebane, Qualla, Lone Star, and Acala, sixteen-sixteenths-inch class; Durango, eighteen-sixteenths; and Snowflake in the twenty-sixteenths-inch class.

In 1925, Durango produced a staple having the greatest uniformity, as shown by its coefficient of variation, $5.67 \pm .38$, while New Boykin was the least uniform in length of staple produced, having a coefficient of variation of $9.82 \pm .67$. In 1926, Harper was the most uniform variety with respect to length of staple, having a coefficient of variation of $5.06 \pm .40$, while Durango, the most variable variety, had a coefficient of variation of $11.15 \pm .86$. The range of the coefficients of variation for the staple length of the individual varieties, with one exception, was distributed between 5 and 10% for both years. The least uniform variety had a coefficient of variation approximately twice as large as the coefficient of the most uniform variety in each of the two years.

TABLE 4.—*Indices of coefficient of variation of staple length 1925 and 1926 cotton varieties, Temple, Texas.*

Variety	Index of coefficient of variation[a]		
	1925	1926	1925–26
Harper	75.83	65.97	70.9
Lankart	78.55	69.23	73.9
Mebane	91.47	78.61	85.0
Cliett's Superior	81.91	97.13	89.5
Belton	99.22	86.70	93.0
Qualla	89.92	97.91	93.9
Rowden	111.88	83.70	97.8
Kasch	88.88	115.51	102.2
Snowflake	123.77	84.09	103.9
Anton	107.49	104.30	105.9
Lone Star	107.62	110.56	109 1
Durango	73.25	145.37	109.3
Truitt	107.88	112.51	110.2
Acala	116.27	118.90	117.6
New Boykin	126.87	109.12	118.0
Sunshine	118.86	120.99	119.9

[a]Mean coefficient of 16 varieties grown in 1925 equal index of 100 for 1925; mean coefficient of same varieties for 1926 equal index of 100 for 1926.

The relative uniformity of each variety for 1925 and 1926 is shown in Table 4, which presents the indices of the coefficients of variation.

From this table it will be seen that Harper, Lankart, Mebane, Cliett's Superior, Belton, and Qualla were more uniform than the average of all varieties for both of the years. The varieties Anton, Lone Star, Truitt, Acala, and Sunshine were consistently more variable than the average for each of the two years. On the other hand, Rowden, Kasch, Snowflake, Durango, and New Boykin were very erratic in their ranking as to uniformity from one season to the other. Rowden, Snowflake, and New Boykin showed the greatest variability in length of staple in the dry season of 1925, while Sunshine and Durango the greatest variation in the wet season of 1926. The Durango variety ranged from the most uniform in length of lint in 1925 to the most variable in 1926. It will be noted that the mean length of Durango for 1926 was only $16.67 \pm .2$, and undoubtedly the commercial seed obtained under the name of Durango in 1926 could not be said to be typical of the variety.

CONCLUSION

The results of the data taken on the individual stalks within each of the 16 varieties grown in 1925 and 1926 justify the following conclusions:

1. A majority of the commonly grown commercial varieties of cotton, as judged by those involved in this study, possess a high degree of variability in staple length. These results emphasize the importance of giving more consideration and attention to uniformity of staple length in cotton breeding. Greater uniformity in length of staple in commercial varieties of cotton is attainable, as evidenced by the fact that certain varieties studied fluctuated over a narrow range and exhibited rather marked uniformity in this respect.

2. Some varieties were consistently uniform as to staple length, even under widely contrasting climatic conditions. Harper, Lankart, Mebane, Cliett's Superior, Belton, and Qualla were varieties which produced consistently a staple comparatively uniform in length in each of the two seasons.

3. Under contrasting seasonal conditions, certain varieties consistently exhibited a high degree of variation. Sunshine, Acala, Truitt, Lone Star, and Anton were consistently more variable than the average of all varieties for the two seasons in which uniformity of staple length was measured.

4. Some of the varieties of cotton which showed considerable variation in length of staple in 1925 were relatively uniform in 1926, while, on the other hand, some of the varieties which were highly variable in 1926 were comparatively uniform in length of staple in 1925.

5. The widely different seasonal conditions existing in these two years apparently had no consistent effect on the variability in length of staple of the different varieties. The mean length of staple of all varieties was slightly shorter in the dry and unfavorable season of 1925, but there was no significant difference in the average coefficient of variability for these two years, even though the range of variability in staple length seems to be wider in the wet than in the dry season.

EFFECT OF SIZE OF SEED SET ON YIELD AND ON CERTAIN OTHER CHARACTERS IN POTATOES[1]

D. C. TINGEY AND GEORGE STEWART[2]

Occasionally there is considerable interest in the question of the proper size of seed set to use in potato production. Many of the experiments that have been conducted are inconclusive. Some have drawn conclusions from experiments without a consideration of the amount of seed planted in each case. Still others have drawn conclusions without a consideration of the relationship that exists between differences in yield and their respective probable errors. Some differences in yield herein reported at first appeared significant, but seem less so after the seed planted is subtracted and the differences compared with their probable errors. In a case or two, however, odds were high enough to appear significant.

REVIEW OF LITERATURE

Stuart, *et al* (12)[3] have given a rather complete review of the literature on size of seed piece in potatoes up to 1922. In view of this, only a few of the earlier and the more recent publications will be considered here. The conclusions reached by Stuart and his collaborators from a study of the literature up to 1922, are as follows:

"A critical study of the literature on the subject leaves the impression that much of the data presented is inconclusive. It also serves to convince the reader that much depends upon the manner in which the experiment was planned and executed whether whole or cut sets gave the most profitable yield.

"The successful determination of the most profitable size of set to use and whether it should be planted whole or cut, primarily involves a careful study of the proper spacing to give to each size of set in order to obtain the maximum yield."

In this same publication Stuart and his colleagues have reported their results of several years of experimental work. The experiments were carried on at Norfolk, Virginia, at Caribou and Presque Isle, Maine, at Greeley, Colorado, and at Jerome, Idaho. The varieties used were Irish Cobbler at the Virginia Station, Irish Cobbler and Green Mountain at the Maine Station, Rural New Yorker No. 2 at the Colorado Station, and Charles Downing (Idaho Rural) and Russet Burbank (Netted Gem) at the Idaho Station.

[1]Contribution from the Department of Agronomy, Utah Agricultural Experiment Station. Approved for publication by the Director, April 17, 1928. Received for publication April 23, 1928.

[2]Assistant Agronomist and Agronomist, respectively.

[3]Reference by number is to "Literature Cited," p. 720.

From the standpoint of yield of marketable tubers, the results are conflicting. However, a definite relationship did exist between the size of set planted and the number of stems and tubers produced to the set. Their conclusions are that the season has a marked influence on the size of the tubers, and conditions which favor a high yield, such as good supply of moisture and plant-food, will insure maximum yields from whole and large-sized cut sets; whereas lack of such conditions favors medium-sized cut sets. This is in direct opposition to data reported by Clausen (3) and by Hill (6, 7).

Clausen (3) reports experiments on size of set which involved several potato varieties planted on soils with various fertilizer treatments. He concludes that heavier seed seemed to be relatively more important on unfertilized than on well-fertilized land. Reports from Wyoming (6, 7) indicate that under adverse conditions, such as a cold wet spring or in droughty years, the larger sets are much more valuable, whereas if conditions are very favorable the differences in yields from large and from small sets are not so pronounced.

Three-ounce sets gave materially better yields in Montana (9) than sets 1½ ounces in size. The larger set gave 11,000 and 4,000 pounds more tubers to the acre than the smaller set from Rural and from Bliss Triumph, respectively. These increases were largely in tubers ranging in size from 2 to 8 ounces. In addition to more tubers to the hill from larger sets, there was also an increased number of stalks to the hill.

Studies on the influence of the size of set on yields and other characters have been reported from three different sections in Idaho, *viz.*, Jerome (12), Aberdeen (1, 2), and Gooding (13).

At Jerome, data were obtained on 1-, 2-, 3-, 4-, 5-, and 6-ounce tubers planted whole, halved (except the 1-ounce tubers), and quartered (except the 1- and 2-ounce tubers). At Aberdeen, data were obtained on 3-, 4-, and 8-ounce tubers planted whole, halved, and quartered. At Gooding, data were obtained on tubers 2 to 3 ounces in size planted whole and halved and on tubers from 4 to 6 ounces and 8 to 10 ounces in size planted whole, halved, and quartered. The Charles Downing (Idaho Rural) and Russet Burbank varieties were used at Jerome, and the Idaho Rural at each of the other two stations. Data were reported from Jerome for 1916 and 1917; from Gooding for 1914 and 1916; and from Aberdeen for 1913 to 1918. The yields from Jerome are on the basis of net prime yield, which is the yield of primes less the seed. The yields from Aberdeen and Gooding were based on the net marketable yield, which is the yield of marketable tubers less the seed. In order to make com-

parisons on a more uniform basis, the data from Aberdeen and Gooding were recalculated by the writers.

The data from Gooding are only approximate, since the size of tuber in the different groups and the distance between the hills varied.

At Jerome, the 4-ounce tubers halved, the 5-ounce tubers halved, the 3-ounce tubers quartered, and the 3-ounce tubers halved gave practically the same net yield of primes. The differences were less than 5 bushels in any case. From all the various sized sets of the Charles Downing variety, the lowest to the highest yield differed by 54.4 bushels. For the Burbank variety the yield of the 4-ounce whole tubers was approximately 8 bushels higher than any other set. The yield from the 3-ounce whole set was second, from the 3-ounce half third, and from the 2-ounce whole fourth. The greatest variation in yield of the four highest was only 23.4 bushels, and the greatest difference in yield from all the sets was 55.1 bushels.

At Aberdeen, the highest net marketable yield came from the 3-ounce tubers halved and was about 9 bushels higher than that from any other set. The yield from the 4-ounce tubers quartered was second, and from the 4-ounce tubers halved third. The greatest difference in the three highest yielding was 25 bushels and the greatest difference from all the sets was 105.1 bushels. The 8-ounce tubers planted whole gave the lowest yield of net marketable tubers.

The 8- to 10-ounce tubers halved gave the highest net marketable yield at Gooding. This was about 18 bushels more than the yield from any other set. The 8- to 10-ounce tubers quartered were second in yield. The greatest variation in all the sets was 151.1 bushels. The 8- to 10-ounce tubers planted whole were lowest in yield of net marketable tubers.

Since the probable error on potato trials is usually rather high, it is doubtful whether in trials conducted as were these a yield difference of less than 30 to 40 bushels in a 200- to 300-bushel yield can be considered significant.

Headley's studies (4, 5) in Nevada led him to conclude that medium-sized tubers (4 to 8 ounces) produce larger yields than smaller tubers (4 ounces or less) from the same bin. He further states that medium-sized whole seed has given better returns than cut seed, though not significantly better.

The conclusions from results obtained in experiments conducted in New Jersey (11) are that with the prices such as prevailed in the period from 1913 to 1921, the 1½-ounce set, while giving larger gross and net yields, did not give a larger cash return than the 1-ounce set.

Later reports (10) indicate that when an equivalent amount of seed is planted from sets of 0.5, 1, and 1.5 ounces in size the smaller sets were the most efficient.

METHODS OF EXPERIMENTATION

The studies herein reported have extended over a period of five years, 1923 to 1927, inclusive. The Rural variety was used each year, except in 1924 when Idaho Rural was used. Two lots of tubers weighing approximately 8 ounces and 4 ounces, respectively, were selected. From each of the lots various sizes of sets were planted. Of the 8-ounce lot, plantings were made from whole tubers, tubers cut in halves, tubers cut into quarters, and tubers cut into eighths. This gave sets approximately 8-, 4-, 2-, and 1-ounce in size, respectively, from the 8-ounce lot. Rows from the 4-ounce lot were planted from whole, halved, and quartered tubers, thus giving approximately 4-, 2-, and 1-ounce sets, respectively, from the 4-ounce lot. Precautions were taken at the time of cutting to get sets as near the desired size as possible and to see that each set had at least one good eye, usually two or more.

Each of the various sized sets from the 8- and from 4-ounce tubers was planted in single rows replicated five times in 1923,[4] 1924, and 1925, six times in 1926, and four times in 1927. The rows were approximately 30 feet long and 30 inches apart, except in 1926 when the rows were 25 feet long and 2 feet apart. The distance between sets was 14 inches in 1923, 1924, and 1925, and 12 inches in 1926 and 1927. The change to closer plantings was made because of the tendency of the Rural variety to get oversized. In spite of this, however, the percentage of marketable tubers was just as high as in previous years, even though conditions were less favorable for potatoes as indicated by lower acre yields. The sets were planted with a shovel the first two years of the experiment. During the last three years deep furrows were made with a one-horse cultivator which had a large shovel attached on the back. A hand-drawn marker was used to mark off the rows to give the desired space between each two sets. After the sets were placed in the furrows a man covered them with his feet, after which the soil was firmed around the sets by tramping on the row. The furrows were opened and the entire planting was usually done within five or six hours which prevented excessive drying of the soil.

During the summer the potato nursery was kept free from weeds and irrigated often enough to keep the vines in a good thrifty con-

[4]Only two replications from the sets from the 4-ounce lot in 1923.

dition. Excellent stands were secured each year from all the various sizes of sets except in 1926 when somewhat poorer stands were obtained. That year (1926), on account of the excessively poor stands in four of the rows, it was thought best to discard those replications entirely. Therefore, two replications of the 8-ounce tubers cut into quarters, one replication of the 8-ounce tubers cut into eighths, and one replication of the 4-ounce tubers cut into quarters were discarded. Since plantings from each size of set was replicated six times in 1926, the omission of one or two replications still left four or five others. Toward fall, either just before or just after the vines were killed by frost, data were taken on height of vine and the number of stems per hill. Since deep furrows were not necessary for irrigation, level culture at least near the plants was practised. In view of this, it was thought that the stem count from above ground would be rather accurate, and, therefore, the data presented were based on such a count. However, a check on the accuracy of the count above ground, as compared to the actual number of stems as determined by counting the stems after the hills were dug, was made during 1927. These data are presented in the discussion on results.

At harvest the tubers were dug with a shovel and data were taken on each row as to the total number and the total weight of the tubers and the number and the weight of marketable tubers. Tubers less than 85 grams in weight were considered unmarketable. Those that were considered as being marketable were uniform, mature, and smooth, and would easily have met the requirements for U. S. Grade No. 1.

EXPERIMENTAL DATA

The data obtained are presented under three headings, *viz.*, (a) the "total net yields," which refers to the total acre yield minus the seed planted in each case; (b) the "net marketable yields," which refers to the yield of marketable tubers minus the seed planted; and (c) the effect of the size of set on certain other growth characters.

TOTAL NET YIELDS

Since the amount of seed necessary to plant an acre varies greatly with the different sizes of sets planted, it appears more accurate to compare results after the seed planted in each case has been deducted from the total yields. It appears that the larger sets, even though giving larger yields, may not be the most economical. This is especially true when 8-ounce whole tubers are planted. The average total acre-yield from the 8-ounce whole tubers was 558.5 bushels as compared with 486.4 bushels for the 8-ounce quartered, or a differ-

ence of 72.1 bushels in favor of the 8-ounce whole tubers. However, when the amount of seed planted in each case is subtracted from the total yield, about equal results are obtained for the five-year period, as shown in Table 1.

TABLE 1.—*The total net yields and percentage of marketable tubers of potatoes obtained from planting sets of various sizes of Rural in 1923 to 1927 at Logan, Utah.*

Size of set	Approximate weight of set in ounces	Total acre yield in bushels less seed 1923	1924[a]	1925	1926	1927	Average yield	Average percentage marketable tubers, 1923–27
8-oz. whole....	8	547.7	529.0	512.9	312.6	387.3	457.9	79.6
8-oz. halved....	4	428.2	487.5	604.2	241.3	319.5	416.1	86.0
8-oz. quartered.	2	458.7	520.7	656.5	287.3	401.8	465.0	90.3
8-oz. eighth...	1	385.8	447.0	587.1	229.5	340.1	397.9	91.9
4-oz. whole...	4	563.9	346.1	678.8	364.9	423.5	475.4	82.7
4-oz. halved....	2	498.3	423.2	680.8	231.7	399.3	446.7	88.2
4-oz. quartered.	1	448.6	378.4	579.8	357.8	372.7	427.5	92.0

[a]Idaho Rural used.

The 4-ounce whole set gave the highest total net yields (Table 1). The yield from the 8-ounce quartered was a close second, being only 10 bushels less than the 4-ounce whole. The 8-ounce whole was third, and the 4-ounce halved was fourth in yield. The maximum variation in the total net yields of the four highest is 28.7 bushels and is probably not significant because it is highly possible that they all come within the probable error, as will be shown later. The total net yields from the 8-ounce eighth and from the 4-ounce quarter are 77.5 and 47.9 bushels, respectively, less than the yields from the 4-ounce whole. This indicates that the 1-ounce set is not as good as a somewhat larger set. There is a very significant relationship between the size of set and the percentage of marketable tubers (Table 1). The percentage of marketable tubers increases with a decrease in the size of set planted, varying from 79.6% for the 8-ounce whole to 92% for the 1-ounce sets.

Since the farmer is primarily interested in those potatoes which he can market, it appears that possibly the better measure of the relative value of the size of set is the net marketable yield.

NET MARKETABLE YIELDS

The term "net marketable yields" is referred to here as the acre yields of salable tubers (heavier than 85 grams) in bushels less the seed planted. Table 2 gives the net marketable yield for each size

of set for each year the experiment was conducted, as well as the probable errors and the odds when the highest yield, which was from the 8-ounce tubers quartered, was taken as a basis.

TABLE 2.—*Net marketable yields from the various sizes of sets with probable errors and the odds when the yields from the 8-ounce tuber quartered is taken as the basis.*

Size of sets	Approximate size of sets in ounces	Net marketable yield, bushels per acre 1923	1924	1925	1926	1927	Average	P.E. in bushels	Odds
8-oz. whole.....	8	485.3	396.3	339.9	233.5	343.7	359.7	10.2	116:1
8-oz. halved...	4	395.9	423.2	489.5	192.9	288.0	357.9	10.1	175:1
8-oz. quartered.	2	450.0	481.6	535.1	266.2	382.4	423.1	12.3	basis
8-oz. eighth....	1	357.6	422.5	523.3	221.7	324.3	369.9	10.7	31:1
4-oz. whole....	4	444.6	327.9	569.5	294.8	377.5	402.9	12.8	1:1
4-oz. halved...	2	422.4	363.9	609.8	204.3	372.7	394.6	12.6	2.6:1
4-oz. quartered.	1	416.5	350.0	506.9	325.4	357.0	391.2	12.7	3:1

It appears (Table 2) from the average net marketable yields that the set from the 8-ounce tuber quartered (2-ounce set) is significantly better than any other size of set from the 8-ounce lot. The odds in favor of the 8-ounce quartered set over the 8-ounce whole set, 8-ounce half set, and 8-ounce eighth set are 116:1, 175:1, and 31:1, respectively. In at least two of the cases the differences probably approach significance. On the other hand, the data do not indicate that the 8-ounce quartered set is any better than any of the sets from the 4-ounce tubers. The odds in favor of the 8-ounce quartered set over the 4-ounce whole, 4-ounce halved, and 4-ounce quartered sets are 1:1, 2.6:1, and 3:1, respectively.

In comparing the same size set from the 8- and 4-ounce tubers, it is interesting to note (Table 2) that the average yield for the 4-ounce whole set is 45 bushels more than the 8-ounce halved set (4-ounce set). The odds in this case are 16:1 in favor of the 4-ounce whole set. On the other hand, the 8-ounce quartered set (2-ounce set) is 28.5 bushels more than the 4-ounce halved set (2-ounce set), though the odds are less than 3:1 that the 8-ounce quartered set is better. For the 1-ounce set cut from the 8- and from the 4-ounce tubers the difference in yield is 21.3 bushels (odds 1.6:1) that the set from the 4-ounce tubers is better.

In conclusion, it can be stated that from these experiments the same size set from either 8- or 4-ounce tubers does not materially affect the yield.

To get an idea as to the ranking order of net marketable yields for each year of the experiment from the various sized sets, Table 3 was

compiled. The sets from the 8-ounce and from the 4-ounce tubers were each considered as a unit. The set giving the highest yield in each case is considered first, the next highest second, etc., for each year. The last column gives the average ranking, which is obtained by summing the yearly ranking and dividing by the number of years which is five.

TABLE 3.—*Ranking order for net marketable yields for the various sets cut from the 8-ounce and 4-ounce tubers.*

Size of set	Approximate size of set in ounces	Ranking 1923	1924	1925	1926	1927	Average rank
8-oz. whole....	8	1	4	4	2	2	2.6
8-oz. halved....	4	4	2	3	4	4	3.4
8-oz. quartered.	2	3	1	1	1	1	1.4
8-oz. eighth....	1	2	3	2	3	3	2.6
4-oz. whole....	4	1	3	2	2	1	1.8
4-oz. halved....	2	2	1	1	3	2	1.8
4-oz. quartered.	1	3	2	3	1	3	2.4

The ranking of the sets from the 8-ounce group is in favor of the 8-ounce tuber cut into quarters (2-ounce set). Four out of the five years it was the highest yielder and during the other year it ranked third. From the 4-ounce tubers the whole and halved sets gave the same average. Each one ranked first in two of the years, second in two of the years, and third one year.

EFFECT OF SIZE OF SET ON CERTAIN OTHER CHARACTERS

The data in Table 4 show some rather interesting relationships between the size of set and certain other characters.

TABLE 4.—*The effect of the size of set on growth characters, average, 1923–1927.*

Size of set	Approximate size of set in ounces	Height of vine, cm	Number stems per hill at surface of ground[a]	Number tubers per stem	Number tubers per hill	Weight per hill, grams	Weight per tuber, grams
8-oz. whole....	8	66.5	6.54	1.66	10.88	1018	103
8-oz. halved....	4	58.9	4.14	1.94	8.02	869	112
8-oz. quartered.	2	59.1	2.77	2.09	5.78	877	154
8-oz. eighth....	1	53.5	1.90	2.53	4.81	753	157
4-oz. whole....	4	66.9	4.67	1.89	8.82	961	115
4-oz. halved....	2	59.8	3.08	2.09	6.43	868	137
4-oz. quartered.	1	59.0	2.17	2.40	5.20	797	162

[a]The figures in this column are slightly higher than actual because the counts were made above ground and some branching occurred beneath the surface. The stem count is also proportionately higher with the larger sets than with the smaller ones, as shown in Table 5.

The larger sets produce a more vigorous plant growth (Table 4). This is shown by the fact that as the size of set increases there is an increase in the number and weight of the tubers per hill, and in the number and height of vines to the hill. On the other hand, the average number of tubers produced on a vine and the average size of the tubers decrease with the increased size of set planted. The decrease in respect to the number of tubers produced to the stem is small but rather uniform.

The fact that larger sets produce hills with a larger number of tubers of a smaller size makes this size of set undesirable when producing commercial table stock because of the larger percentage of culls. However, the larger sets may be used to good advantage in growing potatoes for seed, since medium-sized tubers are more desirable for this purpose.

The seed potato certification standards in Utah require that tubers, in addition to meeting the field inspections, must also meet the requirements of U. S. Grade No. 1, but not exceed 14 ounces in size. This means that tubers ranging in size from about 2.5 ounces to 14 ounces will pass as certified seed, provided they have passed all field inspections. Planting the larger sets tends to reduce the percentage of oversized tubers. At the same time it will give more smaller tubers, but since the 2½-ounce tuber is very small, the undersize percentage is not likely to be so important as those of over-size.

BRANCHING OF STEMS UNDERGROUND

As previously stated, the counts on the number of stems to the hill were made at the surface of the ground. In 1927, in order to check on the accuracy of the aboveground count and to see if the size of set had any influence on the branching underground, the number of stems to the hill was counted at the surface of the ground and again after the hills were dug. The data obtained are given in Table 5.

TABLE 5.—*The extent of branching below the surface of the ground from the different sizes of sets planted, 1927.*

Size of set	Approximate size of set in ounces	Average number of stems per hill: Count before digging	Average number of stems per hill: Count after digging	Difference in percentage
8-oz. whole.....	8	7.2	5.1	29.2
8-oz. halved....	4	4.6	3.4	26.1
8-oz. quartered..	2	3.1	2.6	16.1
8-oz. eighth.....	1	2.1	1.8	14.3
4-oz. whole.....	4	4.7	3.5	25.5
4-oz. halved....	2	3.2	2.7	15.6
4-oz. quartered..	1	2.1	1.8	14.3
Average....		3.9	3.0	

It is evident (Table 5) that considerable branching takes place below the surface. When checked by the actual number as determined after the hills were dug, the stem count taken above ground as an average for all the sets was nearly one stem too many to the hill. The last column in Table 5 gives the percentage difference in the counts made above ground and counts made after the hills were dug. From this it is clear that there is a direct relationship between the size of set planted and the extent of branching which occurred under ground. The larger sets produce hills with proportionately more branching of the vines under ground.

Comparing sets of the same size from the 8-ounce and 4-ounce tubers, it is apparent that there is no appreciable difference.

SUMMARY

From a review of the literature up to 1922 Stuart, *et al* (12) conclude that the proper size of set to plant depends on a number of conditions. The season, the fertility of the soil, the moisture supply, the distance apart sets are to be planted, all are important factors to be considered in determining the proper size of set to use.

The literature published on the results of experiments conducted in the intermountain states, including Montana, Idaho, Wyoming, and Nevada, and the data presented here indicate that sets of about 2 ounces in size, on the average, have given better results.

There appears to be little difference in whole and cut tubers of equal size.

The literature does agree rather uniformly, however, that as the size of the set increases the total weight per hill, the number of tubers per hill, and the number of stems per hill increases, while the percentage of marketable tubers, the average weight per tuber, and the number of tubers per stem decreases.

The experiments herein reported are the results of a five-year study, 1923 to 1927, inclusive. On the basis of total net yields for the five-year period, the 4-ounce whole set, the 8-ounce quartered, the 8-ounce whole, and the 4-ounce half were high. The maximum variation among these four highest yielding sets was 28.7 bushels. When considering the possible errors on the basis of total net yields, it is doubtful if any one of the four highest is any better than any other. The 1-ounce sets cut from both the 8-ounce and the 4-ounce tubers appear to be less desirable.

Possibly, a better measure of the relative value of the various sizes of sets is that based on the net marketable yield. On this basis the 8-ounce tuber quartered (2-ounce set) gave the highest acre yield.

When compared with the 8-ounce whole, 8-ounce halved, and 8-ounce quartered sets the odds are 116:1, 175:1, and 31:1, respectively, that the 8-ounce quartered set is better. The odds here appear significant, at least in two of the cases. On the other hand, however, the 8-ounce tuber quartered is apparently no better than any of the sets from the 4-ounce lot of tubers. The odds in favor of the 8-ounce quartered sets over the 4-ounce whole, 4-ounce halved, and 4-ounce quartered sets is 1:1, 2.6:1, and 3:1, respectively.

A comparison is made of sets of equal size from the 8- and 4-ounce lots of tubers. The odds in favor of the 4-ounce whole (4-ounce set) and the 4-ounce quartered (1-ounce set) sets, as compared with the same size set from the 8-ounce tubers, are 16:1 and 1.6:1, respectively. On the other hand, the odds are less than 3:1 for the 8-ounce quartered (2-ounce set) over the 4-ounce halved (2-ounce set) sets.

The ranking order for net marketable yield is given for each year. Compared on this basis the results from the 8-ounce lot are again in favor of the 8-ounce tuber quartered. From the 4-ounce lot the whole and half sets are about equal in ranking order for net marketable yield.

The effect of size of set on other growth characters was studied. The data show that as the size of set is increased the average height of vine, the number of stems and tubers per hill, and the weight to the hill increases, while the percentage of marketable tubers, the weight per tuber, and the number of tubers per stem decreases.

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EXPERIENCE WITH AN INTENSIVE METHOD FOR HANDLING FIELD EXPERIMENTS WITH FERTILIZERS[1]

G. W. MUSGRAVE[2]

Information in the literature indicates clearly the value of systematic replications in conducting experiments in the field. The value of field experiments is usually questioned when such experiments are conducted in a manner which does not permit the measurement of uncontrolled variation.

Systematic replication of treatments is very common in plant breeding work. In soil fertility and similar studies it has been less commonly used, and while duplicate plats are occasionally found in some experiments, more extensive replications have been very rarely employed.

It is customary in conducting field experiments with fertilizer materials to continue the work over a considerable period of time and the degree of reliability placed upon the conclusions which are drawn is frequently in proportion to the length of time the experiment has been conducted. In those instances where soil variation occurs and in unreplicated series, however, such variation is not necessarily overcome by the extended duration of the experiment but is obviously emphasized thereby.

While an extended interval of time appears to be an essential characteristic of those experiments which deal with residual effects, there are many other types of problems for which earlier established conclusions are a most definite desideratum.

From recent experience gained from the application of intensive methods of experimentation, it seems clear that for certain kinds of problems at least the usual time requirement may not only be considerably reduced but the efficiency in terms of accomplishment and cost may be greatly increased.

The experiments upon which this experience is based are given in Table 1. It will be seen that in several instances the entire experiment has been duplicated at other locations and the results, if concordant, should add further to the confidence which may be placed upon the data.

A specific example will serve to indicate the design of experiment which has been used and the nature of the results secured. For this purpose, one of the smaller experiments has been chosen and the one

[1]Contribution from the American Cyanamid Co., 535 Fifth Ave., New York, N. Y. Received for publication April 26, 1928.

[2]Agronomist.

TABLE 1.—*Experiments on which observations are based.*[a]

Experiment No.	Total number of plats	Number of comparable pairs of treatments	Location of experiment	Duplicate experiment
1	300	30	Rocky Mount, N. C.	No. 2
2	300	30	Oklahoma City, Okla.	No. 1
3	192	48	Lumber Bridge, N. C.	No. 4
4	270	60	Jones, Okla.	No. 3
5	648	72	Rocky Mount, N. C.	No. 6
6	648	72	Jones, Okla.	No. 5
7	324	60	Rocky Mount, N. C.	No. 8 and 9
8	420	60	Jones, Okla.	No. 7 and 9
9	180	30	Columbia, S. C.	No. 7 and 8

[a]Acknowledgment is made to Dana G. Coe, W. H. Rankin, and T. L. Wilkerson who, as regional supervisors, were immediately responsible for the conduct of these experiments.

in which the greatest soil variation occurred, since this will serve to indicate the possibilities under rather less favorable conditions than under the more favorable ones. All of the experiments referred to dealt with cotton and pertained to the general subject of location and method of application of fertilizer materials under typical cotton belt conditions.

OUTLINE OF A TYPICAL EXPERIMENT

The object of this experiment was to compare five methods of application adaptable to the fertilizer distributors commonly in use and employing for each method five different fertilizer materials as follows.

METHODS OF APPLICATION

A—Fertilizer both sides of the seed row, 3 inches from the seed and 2 inches below the surface, applications made the same day as planting and using special attachment for Avery Distributor to provide a split fertilizer stream.

B—Mixed in the row below the seed. Using an Avery Distributor, the fertilizer is applied and incorporated with the soil by the use of a buzzard wing sweep. This is attached behind the fertilizer spout and in front of the rear wheel. The seed is planted *the same day* and in a separate operation.

C—Fertilizer below the seed. Using an Avery Distributor with a deflector attached, the fertilizer is applied in the old water furrow and the bed built upon the fertilizer. This is done *one week before* planting.

D—"Ferris" method. The land is two furrowed two weeks or more before planting, the fertilizer *applied one week before planting* using a 4-inch opener on the distributor, after which the beds are harrowed with a spring tooth cultivator, and the bed finally completed by throwing what additional soil is needed for the purpose on the original two furrows. At planting time, the beds are harrowed down to the same level as the original two furrows, the seed being planted the same day and at the same level as the fertilizer application.

E—Broadcast. The fertilizer is to be broadcast by hand after the beds are prepared and is to cover the area of the plat uniformly from margin to margin. The fertilizer is then to be harrowed into the soil and the seed planted *the same day*.

Treatment A was designed to attain what is considered the ideal location, Treatment B is very similar to the *usual* practise but provides somewhat more thorough mixing of fertilizer and soil than is ordinarily done. Method C has its chief merit in the one week interval between fertilizer application and planting. Treatment D represents as closely as possible the method advocated and in use by Director E. B. Ferris of the South Mississippi Experiment Station. Mr. Ferris has repeatedly referred to the better stand of plants secured on his fertilized plats than on his unfertilized plats. This method of application gives unusually thorough mixing of soil and fertilizer. Method E was included as a method known to be favorable in so far as germination was concerned, but one on which more specific information was desired as to its effect upon later growth, maturity, and yield.

FERTILIZER MATERIALS

1. Complete fertilizer, 10–4–4, deriving all nitrogen from source "I," applied at the rate of 500 pounds per acre.

3. As above, deriving all nitrogen from source "II."

5. As above, deriving all nitrogen from source "III."

7. Nitrogen omitted, 10–0–4, made up with filler (sand) and applied at the rate of 500 pounds per acre.

9. Nitrogen only, 0–4–0, made up with filler (sand) and applied at the rate of 500 pounds per acre.

14. Check plat, no fertilizer.

The plan of the experiment thus includes two sets of variables, *viz.*, (1) methods of application and (2) fertilizer materials, which are superimposable one upon the other. Each of these treatments was replicated six times, thus providing comparable pairs to the number of 30 throughout, as indicated subsequently. In addition there were 12 check plats systematically distributed over the area and also 18 further plats receiving higher rates of application and deriving the nitrogen from source "I." Since the latter 18 plats are supplementary and do not conform to the general plan of the experiment, they may be omitted from the discussion of experimental procedure. The arrangement of the plats is given in Fig. 1. In this figure the plat treatments are indicated by symbols, the first numeral representing the replication, the following letter the method of application, and the final numeral the fertilizer material that was used. The arrangement is systematic throughout and the relative position

of any selected pair of treatments is constant in five out of each six instances. The location of the check plats is such as to be fairly representative of the entire area.

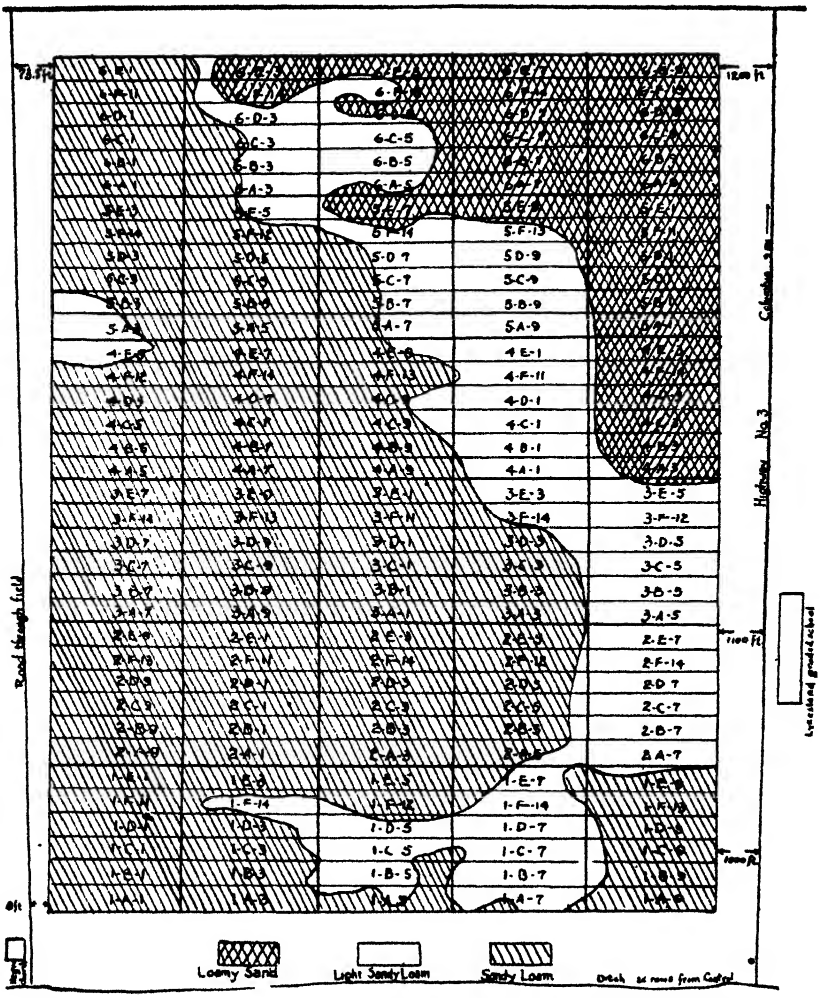

FIG. 1—Diagram showing arrangement of plats in experimental field.

It will be seen that the arrangement permits the use of various statistical devices and other methods for handling the data. The method of pairs may be used throughout, either for fertilizer materials or methods of application. The calculation of the mean yield of the check plats with its probable error also serves to indicate the outside range of uncontrolled variation, which will be less, of course, for the 30 plats of treatments than for 12 of the checks.

DESCRIPTION OF THE EXPERIMENTAL FIELD

The soil variation of the field is also indicated in Fig. 1. The location is in the Coastal Plain and the series is apparently Norfolk with a surface texture of fine sandy loam. Although the field is level and flat to a high degree, some variation in subsoil texture was found which is the principal characteristic represented in the soil map of the experimental area. The field, however, had been originally selected for its uniformity and only after examination of numerous other fields which proved to be less desirable.

RESULTS

The more pertinent data from this experiment include (1) germination or stand counts; (2) form counts, i. e., numbers of white blooms, pink blooms, bolls, and squares; and (3) yield in pounds of seed cotton by pickings.

GERMINATION COUNTS

Stand counts to indicate relative germination were made May 2, 23 days after planting and just prior to the time of chopping. These were made by measuring 33 ⅓-foot sections in the middle portion of each plat and counting all seedlings on three such rows, making a total of 100 feet per plat or 600 feet per individual treatment. Hand tally recording machines were used for the purpose. A strain of pedigreed seed had been obtained from the plant breeding department of the experiment station which was particularly uniform in quality and to which the entire field had been planted with special attention to an even rate of application. Between the period of planting and the making of germination counts, the rain gauge recorded 1.61 inches rainfall and soil moisture conditions during this period were very favorable.

The detailed and summarized counts are given in Tables 2 and 3. The detailed counts show some variation between the totals for each replication, ranging from 15,370 plants for replication two to 20,978 for replication five. The summarized counts by treatments indicate that methods of application C, D, and E have given better germination, on the whole, than have methods A and B. All fertilizer applications by whatever method are inferior, however, to the check or no fertilizer plats.

To determine whether or not the differences between methods of application given in Table 3 are significant, the various pairs of plats have been compared individually and the odds calculated by Student's method. For this purpose, various combinations of pairs may be selected, depending upon their respective locations as indicated in

TABLE 2.—*Germination counts by individual plats.*

Plat No.	Plants per 100 feet	Plat No.	Plants per 100 feet	Plat No.	Plants per 100 feet	Plat No.	Plants per 100 feet	Plat No.	Plants per 100 feet	Total
6-E-1	812	6-E-3	681	6-E-5	764	6-E-7	628	6-E-9	682	
6-F-11	572	6-F-14	702	6-F-12	697	6-F-14	803	6-F-13	458	
6-D-1	814	6-D-3	592	6-D-5	708	6-D-7	744	6-D-9	751	
6-C-1	852	6-C-3	780	6-C-5	787	6-C-7	650	6-C-9	717	
6-B-1	430	6-B-3	524	6-B-5	628	6-B-7	530	6-B-9	443	
6-A-1	615	6-A-3	614	6-A-5	593	6-A-7	450	6-A-9	544	19,565
5-E-3	744	5-E-5	706	5-E-7	650	5-E-9	710	5-E-1	672	
5-F-14	850	5-F-12	526	5-F-14	808	5-F-13	642	5-F-11	528	
5-D-3	814	5-D-5	730	5-D-7	889	5-D-9	686	5-D-1	799	
5-C-3	896	5-C-5	788	5-C-7	864	5-C-9	864	5-C-1	808	
5-B-3	732	5-B-5	687	5-B-7	664	5-B-9	450	5-B-1	732	
5-A-3	499	5-A-5	606	5-A-7	566	5-A-9	569	5-A-1	499	20,978
4-E-5	799	4-E-7	727	4-E-9	791	4-E-1	745	4-E-3	739	
4-F-12	539	4-F-14	760	4-F-13	610	4-F-11	518	4-F-14	853	
4-D-5	770	4-D-7	781	4-D-9	811	4-D-1	714	4-D-3	658	
4-C-5	788	4-C-7	741	4-C-9	712	4-C-1	815	4-C-3	632	
4-B-5	630	4-B-7	601	4-B-9	550	4-B-1	527	4-B-3	592	
4-A-5	496	4-A-7	544	4-A-9	586	4-A-1	522	4-A-3	483	20,034
3-E-7	684	3-E-9	691	3-E-1	628	3-E-3	672	3-E-5	801	
3-F-14	630	3-F-13	478	3-F-11	548	3-F-14	744	3-F-12	413	
3-D-7	611	3-D-9	650	3-D-1	702	3-D-3	584	3-D-5	655	
3-C-7	792	3-C-9	681	3-C-1	612	3-C-3	538	3-C-5	574	
3-B-7	656	3-B-9	638	3-B-1	662	3-B-3	692	3-B-5	590	
3-A-7	718	3-A-9	768	3-A-1	545	3-A-3	679	3-A-5	612	19,248
2-E-9	513	2-E-1	600	2-E-3	579	2-E-5	641	2-E-7	630	
2-F-13	437	2-F-11	304	2-F-14	696	2-F-12	240	2-F-14	683	
2-D-9	593	2-D-1	586	2-D-3	606	2-D-5	528	2-D-7	508	
2-C-9	570	2-C-1	716	2-C-3	652	2-C-5	572	2-C-7	671	
2-B-9	195	2-B-1	305	2-B-3	324	2-B-5	372	2-B-7	583	
2-A-9	448	2-A-1	404	2-A-3	449	2-A-5	408	2-A-7	557	15,370
1-E-1	742	1-E-3	592	1-E-5	607	1-E-7	657	1-E-9	679	
1-F-11	407	1-F-14	722	1-F-12	282	1-F-14	710	1-F-13	442	
1-D-1	728	1-D-3	573	1-D-5	633	1-D-7	613	1-D-9	630	
1-C-1	647	1-C-3	672	1-C-5	648	1-C-7	624	1-C-9	589	
1-B-1	486	1-B-3	439	1-B-5	480	1-B-7	591	1-B-9	426	
1-A-1	601	1-A-3	620	1-A-5	560	1-A-7	556	1-A-9	554	17,510

Fig. 1. That is, Plats 1-A-1 and 1-B-1, 1-A-3 and 1-B-3, 1-A-5 and 1-B-5, etc., to the number of 30 pairs, may be directly compared. In the same manner, comparisons between fertilizer materials may be made using Plats 1-A-1 and 1-A-3, 1-B-1 and 1-B-3, 1-C-1 and

TABLE 3.—*Summarized germination counts of May 2, averages of six replications.*

No.	Fertilizer material	A	B	C	D	E	F	Total	Average
		Plants per 100 feet of row							
1	500 pounds 10–4–4	531	523	742	724	700	—	3,220	644
3	500 pounds 10–4–4	557	550	695	637	668	—	3,107	621
5	500 pounds 10–4–4	546	565	693	671	719	—	3,194	639
7	500 pounds 10–0–4	565	604	723	691	663	—	3,246	649
9	500 pounds 0–4–0	578	450	689	687	677	—	3,081	616
11	1000 pounds 10–4–4	—	—	—	—	—	479	—	479
12	1000 pounds 10–4–4	—	—	—	—	—	449	—	449
13	1500 pounds 10–4–4	—	—	—	—	—	511	—	511
	Total..........	2,777	2,692	3,542	3,410	3,427	1,439	15,848	4,611
	Average.. .	555	538	708	682	685	476	3,169	576
14	Checks, average of 12 plats...........................								747±13.5

1–C–3, etc., thus providing a total of 30 pairs for each fetilizer used. In Table 4 it is seen that methods of application C, D, and E are in fact significantly superior to methods A and B.

TABLE 4.—*Comparison of the effect of methods of application on germination.*

Methods compared	Mean stand		Mean difference	σ	Odds by Student's method
A with B...........	555	538	17	123.2	3.5:1
A with C.... .. .	555	708	153	122.5	9,999:1
A with D....	555	682	127	124.2	9,999:1
A with E..... . ..	555	685	130	90.2	9,999:1

While no direct comparisons may be made in the present instance, and in a similar manner with the check plats which number a total of but 12, the germination on these unfertilized plats appears to be significantly superior to that secured from methods A, B, D, and E and is quite probably superior also to that secured from method C.

An examination of the averages of the six replications of each treatment indicates that the data are not conclusive with respect to the several fertilizer materials applied by any one method. Six plats have usually been insufficient to "smooth out" discrepancies in the results and it is only in the averages of the larger number of plats (30 in the present instance) that reliable figures are obtained.

COUNTS OF FRUITING FORMS

The counts of total fruiting forms shown in Tables 5 and 6 were made on July 18, 28 days after the first blooms were noted and 21 days after blooming became general. These counts were made in the same manner as the stand counts previously noted.

Form counts in cotton are recognized as indicating fairly closely the potential crop possibilities and in this work have usually correlated rather closely with final yields. In cases of subsequent injury to the crops, such as boll weevil, hail or other storm damage, etc., the data on forms have proved of much value, since in such instances yield

figures do not ordinarily correctly reflect the effects of the treatments. In any event, these data are regarded as throwing considerably further light upon the experiment.

TABLE 5.—*Form counts of July 18, averages of six replications.*

No.	Fertilizer material	Forms per 100 feet of row A	B	C	D	E	F	Average
1	500 pounds 10–4–4	1,021.2	1,060.3	1,313.8	1,197.7	921.8	——	1,103.0
3	500 pounds 10–4–4	1,219.2	1,305.7	1,312.5	1,390.7	1,097.7	——	1,265.2
5	500 pounds 10–4–4	1,269.8	1,157.2	1,176.5	1,197.3	1,009.3	——	1,162.0
7	500 pounds 10–0–4	867.3	863.7	855.2	842.3	727.8	——	831.2
9	500 pounds 0–4–0	1,046.7	1,034.2	1,006.0	1,056.0	875.3	——	1,003.6
11	1,000 pounds 10–4–4	——	——	——	——	——	1,248.8	——
12	1,000 pounds 10–4–4	——	——	——	——	——	1,126.2	——
13	1,500 pounds 10–4–4	——	——	——	——	——	1,232.7	——
	Average.........	1,084.8	1,084.2	1,132.8	1,136.8	926.4	1,202.6	1,073.0[a]
14	Checks...							752.5

[a]This average does not include high rates 11, 12, and 13.

TABLE 6.—*Form counts of July 18, bolls as percentage of total forms, averages of six replications.*

No.	Fertilizer material	Bolls as percentage of total forms A	B	C	D	E	F	Average
1	500 pounds 10–4–4	19.86	18.85	19.42	25.00	22.93	——	21.19
3	500 pounds 10–4–4	17.69	21.15	18.84	22.08	27.42	——	21.30
5	500 pounds 10–4–4	18.68	22.76	20.94	25.38	23.20	——	22.69
7	500 pounds 10–0–4	22.10	25.26	24.77	31.56	26.56	——	26.00
9	500 pounds 0–4–0	16.48	19.84	18.36	20.94	19.00	——	18.93
11	1,000 pounds 10–4–4	——	——	——	——	——	25.13	——
12	1,000 pounds 10–4–4	——	——	——	——	——	19.49	——
13	1,500 pounds 10–4–4	——	——	——	——	——	20.35	——
	Average..........	18.80	21.45	20.22	24.58	23.88	21.74	——
14	Checks...							30.23

Treatments C and D have set the most fruiting forms. Treatment E appears definitely inferior to C and D, but superior to the check plats. The high rates of application in series F, which showed reduced germination, have nevertheless shown considerable fertilizer response during the latter part of the season.

The calculation of the percentage of bolls has been found to be of value in indicating the relative maturity of the cotton and in conjunction with the data on percentage of total crop obtained at first picking (Table 10) presents a fairly reliable index of maturity.

The highest percentage of bolls was obtained on the check plats. Of the fertilized plats, those receiving fertilizer by method D appear earlier in maturity than A, B, or C. It may be noted that the plats receiving phosphate and potash only also are earlier in maturity in method D than the plats receiving the same fertilizer applied by

other methods. These results coincide in general with those of Table 10.

YIELDS

The total yields of seed cotton for each of the plats is given in Table 7 and arranged in the same manner as the plats in the field.

Table 7.—*Total yields of seed cotton.*

Plat No.	Pounds per plat	Plat No.	Pounds per plat	Plat No.	Pounds per plat	Plat No.	Pounds per plat	Plat No.	Pounds per plat	Total
6-E-1	11.75	6-E-3	12.00	6-E-5	5.75	6-E-7	5.50	6-E-9	3.25	
6-F-11	24.50	6-F-14	11.25	6-F-12	15.25	6-F-14	5.25	6-F-13	6.00	
6-D-1	13.75	6-D-3	15.25	6-D-5	12.75	6-D-7	7.00	6-D-9	4.50	
6-C-1	19.00	6-C-3	14.25	6-C-5	18.50	6-C-7	8.25	6-C-9	5.75	
6-B-1	17.25	6-B-3	17.25	6-B-5	19.50	6-B-7	6.50	6-B-9	2.25	
6-A-1	17.00	6-A-3	20.00	6-A-5	16.50	6-A-7	6.25	6-A-9	3.00	345
5-E-3	21.00	5-E-5	15.75	5-E-7	14.25	5-E-9	6.25	5-E-1	4.50	
5-F-14	13.50	5-F-12	22.75	5-F-14	15.25	5-F-13	17.75	5-F-11	6.00	
5-D-3	17.75	5-D-5	20.25	5-D-7	15.50	5-D-9	14.50	5-D-1	7.75	
5-C-3	18.25	5-C-5	14.25	5-C-7	14.75	5-C-9	11.50	5-C-1	6.25	
5-B-3	19.75	5-B-5	17.75	5-B-7	18.00	5-B-9	9.50	5-B-1	4.00	
5-A-3	14.00	5-A-5	18.75	5-A-7	12.25	5-A-9	9.75	5-A-1	6.50	408
4-E-5	14.75	4-E-7	13.25	4-E-9	13.50	4-E-1	12.50	4-E-3	9.50	
4-F-12	15.25	4-F-14	13.75	4-F-13	23.25	4-F-11	15.75	4-F-14	6.50	
4-D-5	17.00	4-D-7	16.25	4-D-9	17.75	4-D-1	14.75	4-D-3	9.50	
4-C-5	15.75	4-C-7	11.75	4-C-9	16.25	4-C-1	14.75	4-C-3	9.00	
4-B-5	14.25	4-B-7	11.25	4-B-9	18.25	4-B-1	9.00	4-B-3	12.00	
4-A-5	18.25	4-A-7	14.75	4-A-9	18.50	4-A-1	9.50	4-A-3	7.50	414
3-E-7	14.25	3-E-9	18.75	3-E-1	22.75	3-E-3	19.75	3-E-5	14.00	
3-F-14	13.75	3-F-13	26.00	3-F-11	22.75	3-F-14	12.50	3-F-12	12.00	
3-D-7	12.50	3-D-9	19.25	3-D-1	19.50	3-D-3	19.00	3-D-5	11.00	
3-C-7	9.00	3-C-9	14.25	3-C-1	19.25	3-C-3	17.50	3-C-5	9.00	
3-B-7	10.25	3-B-9	16.00	3-B-1	19.75	3-B-3	17.00	3-B-5	13.00	
3-A-7	8.75	3-A-9	13.25	3-A-1	17.00	3-A-3	13.25	3-A-5	11.75	466.75
2-E-9	9.00	2-E-1	16.25	2-E-3	15.75	2-E-5	14.25	2-E-7	7.25	
2-F-13	16.50	2-F-11	17.25	2-F-14	14.00	2-F-12	21.00	2-F-14	9.00	
2-D-9	14.75	2-D-1	19.00	2-D-3	18.00	2-D-5	15.75	2-D-7	11.50	
2-C-9	11.50	2-C-1	16.25	2-C-3	19.75	2-C-5	14.50	2-C-7	11.00	
2-B-9	13.00	2-B-1	11.75	2-B-3	17.00	2-B-5	13.50	2-B-7	9.00	
2-A-9	7.00	2-A-1	13.00	2-A-3	17.75	2-A-5	13.75	2-A-7	9.00	417
1-E-1	13.25	1-E-3	21.00	1-E-5	16.75	1-E-7	12.50	1-E-9	15.00	
1-F-11	15.50	1-F-14	15.75	1-F-12	17.00	1-F-14	15.00	1-F-13	15.50	
1-D-1	15.00	1-D-3	19.25	1-D-5	16.50	1-D-7	14.00	1-D-9	18.25	
1-C-1	15.25	1-C-3	13.25	1-C-5	16.25	1-C-7	11.00	1-C-9	14.00	
1-B-1	12.00	1-B-3	16.75	1-B-5	13.75	1-B-7	12.50	1-B-9	13.75	
1-A-1	8.75	1-A-3	12.75	1-A-5	15.50	1-A-7	11.75	1-A-9	15.50	443

The summarized yields by treatments are given in Table 8.

TABLE 8.—*Harvested yields of seed cotton.*

No.	Fertilizer material	A	B	C	D	E	F	Total	Average
		Pounds seed cotton, total of six plats							
1	500 pounds 10–4–4	71.75	73.75	90.75	89.75	81.00	——	407.00	81.50
3	500 pounds 10–4–4	85.25	99.75	92.00	98.75	99.00	——	474.75	95.95
5	500 pounds 10–4–4	94.50	91.75	88.25	93.25	81.25	——	449.00	89.80
7	500 pounds 10–0–4	62.75	67.50	65.75	76.75	67.00	——	339.75	67.95
9	500 pounds 0–4–0	67.00	72.75	73.25	89.00	65.75	——	367.75	73.55
11	1,000 pounds 10–4–4	——	——	——	——	——	101.75	——	101.75
12	1,000 pounds 10–4–4	——	——	——	——	——	103.25	——	103.25
13	1,500 pounds 10–4–4	——	——	——	——	——	105.00	——	105.00
	Total	381.25	405.50	410.00	447.50	394.00		2,038.25	
	Average	76.25	81.10	82.00	89.50	78.80			83.87
14	Checks								72.75

The largest yield has been secured from method D which likewise produced the largest number of fruiting forms and the highest percentage of bolls. In germination this method produced significant increases over methods A and B. Method C has ranked second in both fruiting forms and yield. Both the broadcast application E and the attempted side-of-seed position A show results inferior to the other locations and methods included in this experiment.

The comparison of yields by pairs of plats with the calculation of odds by Student's method is summarized in Table 9.

TABLE 9.—*Comparison of effect of methods of application on yield.*

Methods compared	Mean yield		Mean difference	σ	Odds by Student's method
A with B	12.71	13.52	0.81	2.81	14.6:1
A with C	12.71	13.67	0.96	2.80	31:1
A with D	12.71	14.92	2.21	3.04	3,000:1
A with E	12.71	13.13	0.42	4.42	2.3:1

The further maturity data on percentage of total crop which was obtained at the first picking (Table 10) add confirmation to the evidence indicated in Table 6, showing that the method of application as well as the fertilizer materials themselves are effective in modifying the relative maturity of the crop.

FIELD TECHNIC

It is believed that particular attention to technic both in the field and elsewhere is essential for securing data which are sufficiently consistent and which represent a minimum of uncontrolled variation. Numerous items of this kind will occur to any worker handling this

TABLE 10.—*First picking as percentage of total harvest.*

No.	Fertilizer material			Totals of six plats A	B	C	D	E	F	Total
1	500 pounds	1st picking,	pounds	41.75	46.50	59.75	66.25	56.50		270.75
	10-4-4	Total,	pounds	71.75	73.75	90.75	89.75	81.00		407.00
		Percentage		58.18	63.05	65.84	73.81	69.75		66.52
3	500 pounds	1st picking,	pounds	51.75	68.00	56.00	69.25	59.25		304.25
	10-4-4	Total,	pounds	85.25	99.75	92.00	98.75	99.00		474.75
		Percentage		60.70	68.17	60.86	70.12	59.84		64.09
5	500 pounds	1st picking,	pounds	58.25	62.50	51.75	58.50	56.25		287.25
	10-4-4	Total,	pounds	94.50	91.75	88.25	93.25	81.25		449.00
		Percentage		61.64	68.11	58.64	62.73	69.23		63.97
7	500 pounds	1st picking,	pounds	44.50	46.50	45.75	57.00	46.50		240.25
	10-0-4	Total,	pounds	62.75	67.50	65.75	76.75	67.00		339.75
		Percentage		70.91	68.88	69.58	74.26	69.40		70.71
9	500 pounds	1st picking,	pounds	37.25	45.50	42.00	59.00	47.00		230.75
	0-4-0	Total,	pounds	67.00	72.75	73.25	89.00	65.75		367.75
		Percentage		55.59	62.54	57.33	66.29	71.48		62.74
Total 1-9		1st picking,	pounds	233.50	269.00	255.25	310.00	265.50		1,333.25
		Total,	pounds	381.25	405.50	410.00	447.50	394.00		2,038.25
Average 1-9		Percentage		61.24	66.15	62.24	69.44	67.94		65.41
11	1000 pounds	1st picking,	pounds						63.25	63.25
	10-4-4	Total,	pounds						101.75	101.75
		Percentage							62.16	62.16
12	1000 pounds	1st picking,	pounds						64.00	64.00
	10-4-4	Total,	pounds						103.25	103.25
		Percentage							61.98	61.98
13	1500 pounds	1st picking,	pounds						59.00	59.00
	10-4-4	Total,	pounds						105.00	105.00
		Percentage							56.19	56.19
Total 11-12-13		1st picking,	pounds						186.25	186.25
		Total,	pounds						310.00	310.00
Average 11-12-13		Percentage							66.08	66.08
14	Checks	1st picking,	pounds							56.00
		Total,	pounds							72.75
		Percentage								76.97

type of problem. The more important of these items which have been included in the work referred to may be enumerated as follows:

1. Soil selection for uniformity. While the method which has been described is more suitable perhaps to use on experimental areas of a heterogeneous nature than some other methods, uniformity of soil is an important factor in obtaining satisfactory data.
2. The use of three or more rows per plat with resulting data secured by individual rows.
3. Buffer rows, ends, and margins throughout.
4. In cases where two or more individuals are obtaining data from the same experiment, each individual works upon corresponding treatments in separate replications.
5. Actual analyses of all fertilizer materials used.
6. The calibration of fertilizer distributors for each material which is applied.
7. Sufficient farm labor and equipment should be available so that the usual farm operations of plowing, cultivation, etc., for the entire area may be accomplished in a minimum of time.

In handling data it has been helpful to indicate all treatments by symbols rather than names, which are also carried on field markers, and all tabulations and records are thus obtained without specific information upon the individual treatment involved. Also, a system of cross-checking of data from original records is helpful in preventing the insertion of errors from this source.

The experiment which has been cited above was also conducted at two other points (Experiments 7 and 8, Table 1) under a similar plan, with the exception that two rates of application of each fertilizer material were used, thus providing double the number of plats. It is interesting to note that on the basis of this further work the conclusions drawn from the experiment cited were fully substantiated.

SUMMARY

The advantages to be derived from replicated treatments and their value in permitting the measurement of uncontrolled variation is well established. Such methods have been but rarely used in field experiments with fertilizers, however, and little experience with them has been recorded.

A method which has been used with a high degree of satisfaction is described and an example cited. The method embodies the following essentials:

1. But two sets of variables are included in the experiment, one of which is superimposable upon the other (as methods of application of fertilizers and kinds of fertilizer materials).

2. Plat treatments are systematically replicated and distributed throughout the experimental area in checker-board fashion and so

arranged that comparisons may be made between pairs of plats by either variable (methods of application or fertilizers).

3. Plats of 1/40-acre each in size and containing a minimum of three rows each, with all data secured on the basis of individual rows, have proved very satisfactory.

4. Sufficient check plats are included to give an index of the uncontrolled variation (gross) of the experiment.

5. Particular attention is given to securing accuracy in the actual field operations.

The results secured in nine such experiments indicate that the uncontrolled variation may be reduced to within 5% of the mean yield of each variable, and usually has been reduced to 3%. In these experiments a minimum of 30 pairs of comparable plats have been included in each. The mean yields by individual treatments of six replications each, however, have not always been consistent enough to permit drawing conclusions on this lesser number of plats.

The method is recommended as having the following advantages:

1. Uncontrolled variation is satisfactorily measured.

2. On reasonably uniform soil differences to within 15% of the mean yields may be measured to significant limits.

3. The usual protracted time interval required for conducting a field experiment may be considerably reduced.

4. The method is efficient as measured in terms of results and expenditures.

THE RELATION OF SMUT INFECTION TO YIELD IN MAIZE[1]

R. J. Garber and M. M. Hoover[2]

It is usually supposed that corn smut (*Ustilago zeae*) causes a great deal of damage and considerable reduction in yield. It is certainly one of the most common of corn diseases if not the most destructive. Numerous estimates of the extent of injury caused by this fungus have been made, but there seem to have been few, if any, careful studies.

The purpose of the present paper is to present some data dealing with the relation of smut infection to yield and to report further progress in connection with the project in breeding corn for resistance to smut. This work was begun at the West Virginia Agricultural Experiment Station in 1920 and has continued to the present. A report[3] of the work was published in an earlier number of this Journal.

METHODS

The same general plan of experiment has been followed in the last three years as previously, except that each strain of corn has been grown in duplicate rows of 50 single-stalk hills per row and the notes on smut infection have been taken three times during a season, the first after the corn was in silk, the second a month to six weeks later, and the third, to obtain particularly the ear infection, when the corn was husked.

The smut notes were taken on the basis of individual plants and recorded on especially prepared mimeographed sheets. Place, or places, of infection and the size of the smut boils at a given date were recorded. It was found convenient for three persons to work together in taking the notes—two persons examined each individual plant and the third set down the notes.

The method of producing the smut epidemic was similar to that followed previous to 1925. In addition to a heavy application of horse manure in the spring before plowing, an application of manure treated with smut was made when the corn was about knee high.

Many of the selfed strains of corn which were reported in 1925 are still being carried in the nursery and may be supposed to be more nearly homozygous. The practise of discarding the strains (with few

[1]Contribution from the Department of Agronomy, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Approved as Scientific Paper No. 57, by N. J. Giddings, Director of the Station. Received for publication April 30, 1928.

[2]Agronomist and Assistant Agronomist, respectively.

[3]Garber, R. J., and Quisenberry, K. S. Breeding corn for resistance to smut. Jour. Amer. Soc. Agron., 17:132–140. 1925.

exceptions) which proved to be highly susceptible to smut has been continued and for that reason most of the strains now being carried possess some resistance.

DIFFERENCES IN SMUT INFECTION BETWEEN SELFED LINES

The differences in smut infection among the selfed lines reported previously have persisted. A few typical examples are shown in Table 1. The highly susceptible strain (6–10–1–1–1–5–5–1) which was isolated from the Leaming variety has been used as a check for the past three years in both fields where the smut studies have been in progress. Every tenth row was planted with the check and in this way a fairly reliable index of the extent of the smut epidemic was obtained.

In the first column of Table 1 is given the 1927 strain number of the selfed lines. The number of integers separated by dashes in each strain name is the number of years less one that that particular strain had been selfed in 1927. It will be noted that all the lines reported in Table 1 had been selfed seven years in 1927 and for that reason had undoubtedly attained a high degree of homozygosity.

The first five lines listed in the table show consistently a high degree of resistance to smut. The average infection from 1922 to 1927 inclusive ranges from 1.1 to 2.1% and in no year is the infection in any one of the five lines greater than 4.3%. The next four strains listed in Table 1 show a medium high average percentage of smut infection. The first two lines of this group show a relatively low infection in 1922 and 1923 and a high infection from 1924 to 1927 inclusive, whereas the third line (3–8–1–1–1–1–1) of the group shows just the opposite tendency. Line 8–15–1–1–2–1–1–1 showed a low percentage infection in 1922 but has shown a medium high infection since that time. It is reasonable to suppose that these differences in smut infection obtained in the early and in the later years of the selfed lines are, in part at least, of a genetic nature.

LOCALIZATION OF SMUT INFECTION

Several investigators have shown not only that it is possible to isolate selfed strains of maize which differ strikingly with regard to smut infection, but that it is likewise possible to isolate susceptible strains which differ a great deal with respect to place of infection. Some strains may be rather generally infected, others may be infected primarily near the base, others on the ear, and still others in the tassel.

In Table 2 are listed a few strains which have shown a high degree of localization of smut infection. Line 8–1, etc., might be called a

TABLE 1.—*Percentage smut infection in certain strains of selfed maize.*

Name of strain in 1927	1922 Number of plants	1922 Infection	1923 Number of plants	1923 Infection	1924 Number of plants	1924 Infection	1925 Number of plants	1925 Infection	1926 Number of plants	1926 Infection	1927 Number of plants	1927 Infection	Average infection
		%		%		%		%		%		%	%
4-14-2-1-1-1-1-1	52	0.0	24	4.2	20	0.0	86	2.3	82	0.0	43	2.3	1.5
4-17-1-1-1-1-1-1	49	4.1	21	0.0	19	0.0	80	2.5	96	1.0	97	1.0	1.4
4-30-3-2-1-1-1-1	50	4.0	21	0.0	21	0.0	35	0.0	41	2.4	34	0.0	1.1
5- 2-2-1-1-1-1-1	52	0.0	23	4.3	24	0.0	91	0.0	94	1.1	96	1.0	1.1
8-24-1-1-1-1-1-1	52	1.9	25	4.0	24	0.0	89	3.4	93	3.2	76	0.0	2.1
1- 5-1-2-1-1-1-1	53	9.4	25	8.0	25	20.0	92	27.2	98	33.7	31	29.0	21.2
2- 1-1-1-1-1-1-1	37	13.5	25	16.0	19	26.3	31	71.0	65	35.4	91	31.9	32.3
3- 8-1-1-1-1-1-1	51	56.9	16	56.3	72	26.4	25	12.0	77	6.5	16	12.5	28.4
8-15-1-1-2-1-1-1	52	1.9	24	25.0	26	23.1	94	24.5	89	30.3	87	14.9	19.9
6-10-1-1-1-5-5-1	43	46.5	150	23.3	96	77.1	1031	53.6	1015	53.1	819	70.3	54.0

base strain as it has shown more smut boils at the base of the stalk than on any other region of the plant. In 1925, seven plants showed smut boils of which six were at the base of the plants; and in 1926 of the 41 infected plants, 26 were base, 8 more below ear, 2 ear, 4 leaf, and 1 tassel. One of the 26 plants which showed a smut boil at the base also showed smut infection elsewhere on the plant. This is indicated in the table by a 1+. Similarly, in other places in the table where there are two numbers recorded in a single blank, the one with a plus sign indicates the number of plants infected elsewhere with smut in addition to the place indicated in the column heading.

Strains 8–15, etc., 6–30, etc., and 9–7, etc., were predominantly infected in the tassel, whereas strain 6–27, etc., had a rather low tassel but high ear infection in 1925 and a high infection in both ear and tassel in 1926. Strains 5–10, etc., and 1–16, etc., were predominantly infected in the ears, although the latter showed a rather high basal infection in 1926. Strain 10–13, etc., has shown consistently a relatively great number of plants infected with smut in the region of the stalk, immediately below the tassel (neck), and strain 5–3, etc., showed leaf infection only in 1925 to 1927 inclusive. The data in Table 2 indicate clearly that a striking difference in locus of smut infection may be obtained among selfed strains of maize.

INFLUENCE OF SMUT INFECTION ON YIELD OF SELFED LINES OF MAIZE

Smut may lower yield in corn by damaging the ear and thus making it unmarketable, by utilizing plant food nutrients and thus reducing the vigor of the host, or by causing barrenness either directly or indirectly. In 1925 it was decided to make a preliminary study of this question by determining the relative extent of barrenness and also the relative yields of plants infected with smut as compared with those which were not infected within the same selfed strain. By making the comparisons within the same selfed lines which had been selfed for four or five years the possible variability in yields, due to heterozygosity, was largely eliminated.

SMUT INFECTION AND BARRENNESS

In Table 3 are presented the data on relative extent of barrenness collected from 73 selfed lines of maize. In the first column are listed the predominant (if there were such) places of smut infection and in the second column are found the number of selfed lines involved. In the following columns may be found the data which show the extent of barrenness among the smutted and among the smut-free plants. By means of the percentages recorded in the columns headed "Percentage of barren smut-free plants" and "Per-

TABLE 2.—*Location of smut infection in certain selfed strains of maize.*[a]

Name	Year grown	Number of plants	Number of plants infected in					
			Tassel	Neck	Leaf	Ear	Below ear	Base
8- 1-1-1-1-1	1925	30	1					6
8- 1-1-1-1-1-1	1926	94	1		4	2	8	26 1+
8-15-1-1-2-1	1925	94	22					1
8-15-1-1-2-1-1	1926	89	25		1	1		
8-15-1-1-2-1-1-1	1927	87	10				3	
6-30-2-1	1925	87	14					3
6-30-2-1-1	1926	94	38				2	
6-30-2-1-1-1	1927	86	27					
9- 7-1-1	1925	88	36 2+		1			
9- 7-1-1-1	1926	84	30		1		1	2
6-27-1-1-1	1925	56	2		3	10		
6-27-1-1-1-1	1926	90	29 5+			9		
5-10-1-1-1-1	1925	94	3 2+	1	5 1+	21 2+		
5-10-1-1-1-1-1	1926	100	9			25 1+		
1-16-1-1-1-1	1925	39	2	8		10 5+	3	1
1-16-1-1-1-1-1	1926	57	3	1		12 4+	9 2+	13 5+
1-16-1-1-1-1-1-1	1927	96				4		
10-13	1926	95		9 2+	1		2	
10-13-1	1927	83		22 6+	1	1	4	
10-13-2	1927	83		30 2+	1		4	
5- 3-1-1-1-1	1925	69			4			
5- 3-1-1-1-1-1	1926	82			5			
5- 3-1-1-1-1-1-1	1927	6			3			

[a]A smut boil below the second internode at the base of the plant was considered as basal infection. Between this region and the node at which the ear appeared was considered "below ear." The "neck" was considered immediately below the tassel. Leaf sheath was included with leaf.

TABLE 3.—*Percentage of barrenness among smutted plants and among smut free plants in certain selfed strains of maize in 1925.*

Place of infection	Number of selfed strains	Number of smut-free plants	Number of barren smut-free plants	Percentage of barren smut-free plants	Number of smutted plants	Number of barren smutted plants	Percentage of barren smutted plants
Tassel	7	182	54	29.7	73	19	26.0
Leaf	9	152	13	8.6	87	31	35.6
Tassel and neck	6	118	26	22.0	43	19	44.2
Neck and below ear	16	197	21	10.7	275	97	35.3
Below ear	26	373	100	26.8	298	136	45.6
Scattered	9	166	21	12.7	92	28	30.4

centage of barren smutted plants" it is possible to make a direct comparison of the extent of barrenness among the plants infected with smut and those not infected. It will be observed that in all cases except in the seven "tassel" strains the percentage of barrenness among the smut-infected plants is much higher than among the non-infected plants. The "tassel" strains showed a slightly higher percentage of barrenness among the smut-free plants than among the smutted ones. The 9 "leaf" strains showed about four times as great; the 6 "tassel and neck" strains about twice as great; the 16 "neck and below ear" strains a little over three times as great; the 26 "below ear" strains not quite twice as great; and the 9 "scattered" strains about two and one-half times as great a percentage of barrenness among the smutted plants as among those that were smut free. The data show that smut infection may cause an appreciable amount of barrenness.

SMUT INFECTION AND YIELD

In order to obtain a measure of the difference in yield between infected and non-infected plants, individual plants of each strain were harvested separately. The ear or ears from each plant were placed in a properly numbered paper bag and all the paper bags containing the ears from the smutted plants of one selfed strain were placed in a burlap bag.

Similarly, all the ears from the smut-free plants of the same particular selfed strain were placed in another burlap bag. This material was hung in a drying room and later the ears were shelled and the yields determined. The comparison between average yields was made by the method suggested by Student. The average yield of the smut-free plants was paired with the average yield of the smutted plants in the same selfed strain.

The data are shown in Table 4. In the first column the nature of the infection and in the second column the number of selfed strains are shown. The number of plants involved, the mean difference in yield, and the significance of these differences are shown in the last four columns of the table.

There were five "tassel" strains, i.e., strains infected with smut predominantly in the tassel, involving a total of 46 smutted and 96 smut-free plants with a mean difference in yield of —20.1 grams. The minus sign indicates that the difference is in favor of the smutted plants. This is the only instance in which a statistically significant difference between average yields was obtained as is shown in the last column of the table. The five "leaf" strains also showed a difference in mean yield in favor of the smutted plants, but the difference is not

significant. The smut-free plants of the "neck and below ear," "below ear," and "scattered" strains yielded on the average somewhat more than the smut-infected plants but not significantly more.

In view of the fact that selfed lines of corn are somewhat unsatisfactory for making yield determinations and the further fact that the results obtained were at variance with expectations, it was decided to repeat the investigation with F_1 crosses between selfed lines.

TABLE 4.—*Influence of location of smut infection on yield of certain selfed strains in maize, 1925.*

Place of infection	Number of selfed strains	Number of plants Smutted	Number of plants Smut free	Mean difference in yield, grams[a]	P
Tassel.	5	46	96	—20.1	163 to 1
Leaf.	5	38	81	—11.9	10 to 1
Neck and below ear	15	161	172	+11.6	11 to 1
Below ear.	15	118	204	+ 6.3	7 to 1
Scattered.	9	64	145	+10.3	5 to 1

[a]+ = Smut free; — = Smutted.

INFLUENCE OF SMUT INFECTION ON YIELD IN F_1 CROSSES IN MAIZE

Crosses were made between certain selfed lines which were more or less susceptible to smut with the idea of obtaining F_1 hybrid vigor and hence a more favorable host for studying the relation between smut infection and yield. Then, too, by using only F_1 plants from selfed lines the same advantages with respect to uniformity of genotype are obtained as in the case when the selfed lines themselves are used. The relative yield and the degree of barrenness were studied in the smut-infected and the non-infected first generation hybrids in a manner somewhat similar to that followed in the selfed lines.

The history of the first generation crosses used in this study and the percentage of smut infection obtained are shown in Table 5. The last column of the table shows clearly that there was a great deal of difference among the first generation progeny with respect to smut infection. Cocke's Prolific x Leaming and the reciprocal showed 92.5 and 85.5% smut infection, respectively, whereas Knight's White x Cocke's Prolific showed an infection of 16.6% and Golden Glow x Reid's Yellow Dent an infection of 38.5%.

SMUT INFECTION AND BARRENNESS

In Table 6 the relative degree of barrenness among the F_1 plants infected with smut and those not infected is shown. Here, as with the selfed lines, the smutted plants showed a somewhat greater relative number of barren individuals than did the plants that were free

from smut. One exception to this was found in the Cocke's Prolific x Leaming, although in this case, if both the cross and its reciprocal are considered, the percentage of barrenness among the smutted plants is the greater. Considering all the F_1 plants together, the barrenness among the smut-free plants was 0.6% and among the smutted plants 6.6%. This is definite evidence that the smut fungus caused an appreciable amount of barrenness among the F_1 plants.

TABLE 5.—*Percentage of smut infection of certain F_1 crosses in maize in 1927.*

Name	Total number of plants	Number of smut-free plants	Percentage of smut-free plants	Number of smutted plants	Percentage of smutted plants
G.G.[a] x R.Y.D.[b]	226	139	61.5	87	38.5
C.P.[c] x L.[d]	160	12	7.5	148	92.5
L. x C. P.	282	41	14.5	241	85.5
K. W.[e] x C. P.	332	277	83.4	55	16.6

[a]Strain of Golden Glow which had been selfed for six years.
[b]Strain of Reid's Yellow Dent which had been selfed for four years.
[c]Strain of Cocke's Prolific which had been selfed for six years.
[d]Strain of Leaming which had been selfed for six years.
[e]Strain of Knight's White which had been selfed for four years.

TABLE 6.—*Percentage of barrenness among smutted plants and among smut-free plants in certain F_1 crosses in maize in 1927.*

Name	Number of smut-free plants	Number of barren smut-free plants	Percentage of barren smut-free plants	Number of smutted plants	Number of barren smutted plants	Percentage of barren smutted plants
G. G. x R. Y. D.	139	0	0	87	1	1.1
C. P. x L.	12	1	8.3	148	10	6.8
L. x C. P.	41	2	4.9	241	23	9.5
K. W. x C. P.	277	0	0	55	1	1.8

SMUT INFECTION AND YIELD

The yields of F_1 plants were determined in a manner entirely analogous to that used earlier in determining the individual plant yields of certain selfed lines.

In Table 7 are shown the average yields of the smut-free plants and of the smutted plants, the differences between the averages, and the significance of these differences. In only one case, namely, Golden Glow x Reid's Yellow Dent is a difference obtained which is as much as four times its probable error and this difference is in favor of the smutted plants. Similarly, in the Cocke's Prolific x Leaming cross and in the reciprocal the plants infected with smut produced, on the average, a somewhat greater yield than did the smut-free plants, but the differences between them are only 2.5 and 2.2 times their respective probable errors. The Knight's White x

Cocke's Prolific cross showed a slightly greater average yield of the smut-free plants but such a slight increase as to be of no significance.

TABLE 7.—*Yield of smutted and smut-free plants of certain F_1 crosses in maize grown in 1927.*

Name	Smut free (+) Number of plants	Smut free (+) Mean, *Grams*	Smutted (—) Number of plants	Smutted (—) Mean, *Grams*	Difference, *Grams*	Difference / P. E.
G.G. x R.Y.D.	139	204.3±3.0	86	224.4±3.9	—20.1±4.9	4.1
C.P. x L.	11	181.8±15.3	138	220.7±3.9	—38.9±15.8	2.5
L. x C.P.	39	172.4±7.7	218	190.1±2.8	—17.7±8.2	2.2
K.W. x C.P.	277	240.6±3.4	54	238.4±6.2	2.2±7.1	0.3

In view of these somewhat disconcerting results, it was decided to compare, by using Student's method, the yield of smut infected F_1 plants with the yield of adjacent, non-infected plants of the same F_1 cross. In no case were the yields of infected and non-infected plants paired unless they were growing within three hills (45 inches) of one another. It was usually possible to pair the yield of an infected plant with that of one not infected growing in an adjacent hill.

In pairing the yields the place of smut infection was also taken into account. It may be observed from the first three columns of Table 8 that the yields of 40 individual plants infected in the tassel with smut were paired with the yields of 40 nearby plants free from smut of the F_1 cross Golden Glow x Reid's Yellow Dent. In a similar manner other pairs were made up and the mean difference and the odds calculated. The last column of the table shows that in only two cases were differences obtained which were statistically significant by Student's criterion and in both of these cases the plants infected with smut yielded more on the average than did the plants free from smut. These results were hardly expected, but they are all the more interesting because they tend to corroborate the results obtained with the selfed lines. For some reason tassel-infected plants yielded somewhat more on the average than did plants of the same genotype but not infected with smut.

In two instances, "base" infected of the Knight's White x Cocke's Prolific and "below ear" infected of the Golden Glow x Reid's Yellow Dent, the smut-free plants yielded somewhat more on the average than the smut-infected plants, but the differences were not significant. In all other cases the differences in average yields were in favor of the smutted plants, but in only two instances as has been pointed out above were the differences highly significant.

TALBE 8.—*Influence of location of smut infection on yield as shown by adjacent paired plants among certain F_1 hybrids of maize.*

Name	Place of infection	Number of pairs	Mean difference[a]	P
G.G. x R.Y.D...	Tassel	40	—14.5	Over 300 to 1
G.G. x R.Y.D...	Below ear	16	+ 2.6	4 to 1
L. x C.P........	Tassel	21	—29.6	1,205 to 1
L. x C.P........	Tassel and below ear	17	—12.7	14 to 1
L. x C.P........	Neck	14	— 1.2	No significance
L. x C.P........	Below ear	13	— 5.2	2 to 1
K.W. x C.P.....	Base	34	+ 5.9	10 to 1

[a] + = Smut free; — = Smutted.

DISCUSSION

The influence of smut on yield in maize one would naturally suppose to be dependent on a number of factors such as time, place, and extent of infection. It would be reasonable to expect that a strain of corn very susceptible to smut on the ear would be damaged considerably. As a matter of fact the entire ear is frequently supplanted by a mass of smut spores in which case complete barrenness of the host plant results. In other instances a large smut boil may form on the stalk just below the ear and also cause barrenness. In view of the investigation reported here, induced barrenness of the host because of the smut fungus seems to be the most important factor in reducing the yields. In fact it was impossible to demonstrate that the presence of the smut in those cases where barrenness of the host was not induced lowered yield significantly. On the contrary, the average yield of the plants infected with smut in the tassel only actually was more than plants of the same genotype but not infected with smut. This is perhaps somewhat contrary to expectation.

The difference in yield in favor of the "tassel"-infected plants might be explained in at least two ways. The smutted plants on the average may have been somewhat more vigorous because of favorable conditions for growth and therefore somewhat more liable to infection, or the slight infection (in most tassel infections the smut boils were small) may have acted as a stimulant and produced a somewhat more vigorous growth of the host.

In this investigation the damage due to a lowering of the quality of the ears because of the presence of smut was not taken into account. Smut damage amounts to an appreciable reduction in yield of high quality ears and therefore should not be disregarded in reckoning the loss due to the fungus.

The investigation carried on at the Minnesota Experiment Station and the one reported here certainly show that not only is it possible to

isolate selfed strains of maize which differ strikingly with respect to resistance to smut, but also that certain strains are predominantly susceptible to smut in certain regions of the plant. It would be very interesting to seek the cause of this localization of infection. It hardly seems possible that it is due to different biological forms of the smut because a selfed line of maize predominantly infected in the tassel may be found growing beside another selfed line predominantly infected at the base. It seems to the writers that the explanation for this difference, whether physiological or morphological, will be found in the host plant itself.

CONCLUSIONS

Selfed lines of maize may be isolated which differ sharply with respect to resistance to smut. Susceptible lines also differ strikingly with respect to localization of smut infection, some are rather generally susceptible and others are predominantly susceptible in certain regions of the plant.

The greatest reduction in yield, owing to smut, among corn plants of the same genotype was brought about by barrenness of the host induced by the fungus. The barrenness among 1,188 smut-free plants from selfed lines was 19.8% as compared with 38.0% among 868 smutted plants from the same selfed lines, whereas the barrenness among 469 smut-free F_1 plants was 0.6% and among 531 similar F_1 plants infected with smut was 6.6%.

In this investigation it has not been possible to demonstrate a significant decrease in yield owing to smut infection among corn plants of the same genotype other than that caused by barrenness of the host induced by the fungus.

Corn plants infected with smut in the tassel only yielded on the average more than did plants of similar genetic constitution but free from smut. This was demonstrated both in selfed lines and in F_1 crosses between selfed lines.

RELATION OF SORGHUM ROOTS TO CERTAIN BIOLOGICAL PROCESSES[1]

B. D. WILSON AND J. K. WILSON[2]

A soil which has been planted to sorghum becomes less productive with respect to certain succeeding crops. While agronomists do not agree as to the cause of this condition, it is usually ascribed (a) to the action of a toxic substance contained in the residues of sorghum or formed during their decomposition, or (b) to a curtailment in the quantity of nitrogen available for higher plants resulting from the presence in the soil of carbonaceous material of relatively high solubility. In the latter case, it is claimed that plants growing in a soil on which sorghum previously grew are compelled to compete for their nitrogen with those soil organisms which are activated by the presence of soluble organic matter. The views of Brezeale (1)[3] and of Conrad (2) are representative, respectively, of these two interpretations.

EXPERIMENTAL

Data which may have some bearing on the cause of the injurious after-effects of sorghum are presented in the present paper. They were obtained in this laboratory where tests were made of the relative effects of corn and sorghum roots (a) on nitrate accumulation in soil, (b) on the growth of an organism known to assimilate nitrate nitrogen and to oxidize carbonaceous material, and (c) on the evolution of carbon dioxide from soil.

The soil used in the experiments to be described was Dunkirk gravelly sandy loam which is low in organic matter but of rather high productivity. The corn (*Zea mays indentata*) and sorghum (*Holcus saccharatus*) roots employed in the investigation were dug from the field, dried at room temperature, and ground to pass a 100-mesh sieve.

DISAPPEARANCE OF NITRATES IN SOIL CULTURES CONTAINING ROOTS OF CORN OR SORGHUM

In a previous laboratory study (7) with the roots and hay of timothy and clover it was found that 0.5 gram of these organic materials in 100 grams of soil provided a period of convenient length for supplied nitrates to first disappear and later reappear in soil

[1]Contribution from the Department of Agronomy, New York State College of Agriculture at Cornell University, Ithaca, N. Y. Received for publication May 5, 1928.

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[3]Reference by number is to "Literature Cited," p. 754.

cultures. In the light of this experience, 0.5 gram of corn or sorghum roots was mixed with 100 grams of soil and transferred to 300-cc Erlenmeyer flasks. The resulting cultures were brought to optimum moisture content with a solution of $Ca(NO_3)_2$ and held at this degree of saturation by means of distilled water. Similar cultures, containing no added roots, were employed and incubated simultaneously with those containing roots. All cultures were held at 25°C and at frequent intervals the quantity of nitrates present in them was determined by means of the phenoldisulfonic-acid method. Representative cultures at the beginning of the experiment were found to contain 12 p. p. m. of nitrate nitrogen in dry soil. The results of this test are recorded in Table 1. No determinations for nitrates were made until the cultures had incubated for three days. At that time nitrates had completely disappeared from the soil with sorghum roots, but it was not until after the sixth day that they had disappeared from the soil with corn roots. Nitrates did not reappear in the cultures with roots until the incubation period had exceeded seven weeks, and nitrates were still low in the cultures at the end of eleven weeks. In the soil to which no roots were added, a gradual accumulation of nitrates ensued, and at the end of the experiment they had reached a relatively high figure.

The experiment was repeated, but in this case with a more concentrated solution of $Ca(NO_3)_2$, or one that was equivalent to 40 p. p. m. of nitrate nitrogen in dry soil. This was done, because the results of the preceding experiment seemed to indicate that the characteristic effects of the corn and sorghum roots on nitrate accumulation might be accentuated in the presence of a stronger solution of $Ca(NO_3)_2$. The results are shown in Table 2. Nitrate accumulation was not depressed materially in the soil containing corn roots for several weeks, yet in the soil containing sorghum roots nitrates were absent at the end of the third day when they were first determined. The corn roots did not initiate an effect on the accumulation of nitrates until about the time they began to reappear in the cultures with sorghum roots. At the end of the incubation period (11 weeks), the soil to which no roots were added contained approximately twice as much nitrate nitrogen as did the soil to which roots were added.

TABLE 1.—*Disappearance and reappearance of nitrate nitrogen in p. p. m. of dry soil in unsterile soil cultures containing the roots of corn or sorghum.*

(Nitrate nitrogen introduced, 12 p. p. m. of dry soil)

	Incubation period, days											
	3	6	10	21	28	35	42	49	56	63	70	77
Soil containing 0.5 gram of corn roots...	9	2	0	0	0	0	0	0	10	16	7	7
Soil containing 0 5 gram of sorghum roots	0	0	0	0	0	0	0	0	tr.	4	11	14
Soil containing no added roots.........	15	13	16	30	25	28	38	38	40	50	33	60

Determinations of the quantity of soluble organic matter contained in the roots using as solvents both distilled water and a solution of $Ca(NO_3)_2$ showed the sorghum roots to contain a much larger quantity of this material than did the corn roots. The values obtained with the two solvents did not differ materially. It was found that 2.21 grams of corn roots were required to yield as much soluble organic matter as did 0.75 gram of sorghum roots when distilled water was used as a solvent.[4]

TABLE 2.—*Disappearance and reappearance of nitrate nitrogen in p. p. m. of dry soil in unsterile soil cultures containing the roots of corn or sorghum.*

(Nitrate nitrogen introduced, 40 p. p. m. of dry soil)

	Incubation period, days								
	3	7	10	14	21	42	49	63	77
Soil containing 0.5 gram of corn roots...	33	45	50	38	33	6	16	15	48
Soil containing 0.5 gram of sorghum roots	0	0	0	2	1	23	26	45	54
Soil containing no added roots.........	39	45	43	43	40	68	80	100	100

In adding equal quantities of the corn or sorghum roots to the cultural flasks a larger initial quantity of soluble organic matter was obviously introduced into those cultures containing sorghum roots. It occurred to the writers that, if the corn and sorghum roots were so employed as to introduce equal quantities of soluble organic matter into the soil cultures, the rate of nitrate disappearance in the presence of each of these might be more nearly the same. Such an experiment was designed, the cultures being brought to optimum moisture content with a solution of $Ca(NO_3)_2$ equivalent to 65 p. p. m. of nitrate nitrogen in dry soil. The results of this work are presented in Table 3. The smaller quantity of sorghum roots was markedly more effective in bringing about an immediate disappearance of nitrates than was the larger quantity of corn roots. Since the cultures contained equal quantities of soluble organic matter at the beginning of the experiment, it may be inferred that the quality of the organic

TABLE 3.—*Disappearance of nitrate nitrogen in p. p. m. of dry soil in unsterile soil cultures containing the roots of corn or sorghum.*

(Nitrate nitrogen introduced, 65 p. p. m. of dry soil)

	Incubation period, days							
	1	2	3	4	5	7	10	16
Soil containing 2.21 grams of corn roots.....	36	26	50	33	26	9	4	2
Soil containing 0.75 gram of sorghum roots..	9	tr.	0	0	0	0	0	4
Soil containing no added roots.............	63	50	63	55	40	50	25	60

[4]These weights of roots were used since they gave the same quantity of soluble organic matter as was contained in 0.5 gram of alfalfa roots with which these experiments were concerned when planned. The nitrogen content of the corn and sorghum roots was 0.57% and 0.44%, respectively.

matter of sorghum roots is more effective in causing a disappearance of nitrate nitrogen in soil than is that of corn roots. In the preceding experiment a less rapid disappearance of nitrates occurred with corn roots than is attributed to them in the present one. This is due, no doubt, to the larger quantity of corn roots used in the latter experiment.

BACTERIAL COUNTS

If the roots of sorghum are more conducive to a disappearance of nitrates in soil than are the roots of corn because of a greater stimulation of those soil organisms which decompose organic matter with the assimilation of nitrates, the organisms in question should multiply more rapidly in the presence of sorghum roots than in the presence of corn roots. In support of this assumption, the growth of an organism, designated in this laboratory as "guttation," was observed when inoculated into soil cultures containing either the roots of corn or sorghum. This bacterium, isolated from the water of guttation of corn, is a rapid-growing organism. It assimilates both nitrates and ammonia and has the property of oxidizing a large variety of carbohydrate material. It also forms large and characteristic colonies when grown on agar plates. The habits of this organism were well understood, since it had been used in a former investigation (7) having to do with the relative effects of timothy and clover residues on nitrate accumulation.

The method developed at that time for growing and counting the organism was again employed. It consisted essentially in mixing 1 gram of roots with 100 grams of soil, transferring the mixture to a 300-cc Erlenmeyer flask, and inoculating with 25 cc of a suspension of "guttation" in distilled water. Cultures prepared in this way were incubated at 25°C until they were used for plating. The cultures were plated by transferring the entire contents of a flask to a water blank from which proper dilutions were made. The organism was developed on plates, a nutrient-agar medium containing 1.5% of glucose being used. If the medium as made up did not have a reaction of approximately pH 6.5, it was adjusted with sodium hydroxide to bring about this reaction. All plates were incubated at 25°C for 24 hours and the colonies of "guttation" appearing on them were counted. No difficulty was experienced in counting the colonies. The organism grew rapidly enough when plated from unsterile soil to produce colonies that could be counted before those of other organisms appeared.

The counts obtained for the growth of "guttation" in soil containing the roots of corn or sorghum are presented in Table 4. The

TABLE 4.—*Growth of "Guttation" in thousands of organisms per gram of soil in unsterile soil cultures containing the roots of corn or sorghum.*

(Cultures inoculated with 3,000,000 organisms per gram of soil.)

Soil containing	Incubation period, days					
	1	2	3	6	9	
1 gram of corn roots	178,700	128,750	14,375	5,150	2,300	
1 gram of sorghum roots	205,000	302,500	90,000	60,000	2,150	
No added roots	18,750	10,000	6,000	2,400	475	
	13	17	20	24	28	34
1 gram of corn roots	1,500	925	625	166	215	116
1 gram of sorghum roots	1,966	963	281	100	108	40
No added roots	462	50	253	94	113	19

figures for counts shown are the averages for four plates. The organism multiplied more rapidly in the cultures containing sorghum roots than in those containing corn roots at each plating until after the sixth day. The higher counts obtained for the sorghum cultures during the first week of the test suggest that during this period the organic matter of sorghum roots is more easily assimilated by the organism than is that of corn roots. The fall in the counts is attributable, no doubt, to the exhaustion of the more soluble organic matter of the organic residues. That the organic matter of both sorghum and corn roots greatly increased the growth of "guttation" is shown by the lower counts for those cultures to which no roots were added. The findings revealed in the table under discussion were substantiated in subsequent trials with the same soil and, also, with Dunkirk silty clay loam, which is a much heavier soil.

EVOLUTION OF CARBON DIOXIDE FROM SOIL CULTURES CONTAINING ROOTS OF CORN OR SORGHUM

The results of the previous experiments which seem to indicate that the organic matter of sorghum roots is more rapidly oxidized in soil than is that of corn roots were supported when the evolution of carbon dioxide from soil cultures containing these roots was measured. This was done by determining the evolution of carbon dioxide from cultural flasks containing 100 grams of unsterile soil in which 1 gram of the ground roots of corn or sorghum was incorporated and which were brought to optimum moisture content with distilled water. Some of the flasks were aspirated immediately for carbon dioxide; others were incubated at 30°C and aspirated at later periods. Aspirations were conducted for 24 hours and carbon dioxide was determined by means of the method recommended by Truog (5).

TABLE 5.—*Milligrams of carbon dioxide evolved in unsterile soil cultures containing the roots of corn or sorghum.*

(Aspirated for 24 hours)

	Age at end of aspiration, days							
	1	2	3	4	7	8	9	10
Soil containing 1 gram of corn roots	40.6	36.7	20.3	14.1	8.6	14.8	16.4	17.2
Soil containing 1 gram of sorghum roots	55.5	107.8	132.0	46.9	13.3	14.1	23.4	14.1
Soil containing no added roots	11.7	32.8	5.5	4.7	2.3	5.5	5.5	5.5

The data resulting from this test are to be seen in Table 5. During the first few days of the experiment, more carbon dioxide was given off from the cultures containing sorghum roots than from those containing corn roots. Serving as a source of readily available energy, the greater quantity of soluble organic material present in the sorghum roots is believed to be responsible for this relationship.

DISCUSSION

Under the conditions of these experiments, sorghum roots were found to be more immediately active than were corn roots in stimulating in soil certain biological processes which are associated with nitrate accumulation, bacterial growth, and the oxidation of organic matter as measured by the evolution of carbon dioxide. That these processes are intimately associated with the quantity of available nitrogen present in soil at any one time is fully recognized.

The observations of Conrad (2) suggest that the injurious after-effects of sorghum may be assigned to a lack of available nitrogen for succeeding crops. Finding that the addition of nitrogen to soil alleviated this condition and that the roots of sorghum contained considerably more sugars than did the roots of corn, he concluded that the larger quantity of soluble organic matter of sorghum roots caused the organisms of the soil to be increased in numbers, accompanied with the removal of available nitrogen from the soil solution. The results of the present investigation appear to support this contention. The writers found that sorghum roots not only contain a larger quantity of soluble organic matter, but that the quality of this material is of such a nature as to be more effective in bringing about a disappearance of nitrate nitrogen in soil than is that of corn roots.

The theory has been advanced by Breazeale (1) that a toxic condition follows the growth of sorghum which destroys, to a large extent, the flora of the soil that oxidizes organic matter. This assumption is not in accord with the results of this paper, if the growth of "guttation," in the presence of sorghum roots, may be used

as a meausre. While it can not be stated that other soil organisms which oxidize organic materials with the assimilation of nitrate nitrogen would behave in a similar way to that of "guttation," there seems to be no reason for believing otherwise.

Waksman and Skinner (6), Martin (4), and others have shown that the addition to soil of organic materials, varying in character, brings about an increase in the numbers of the micro-organisms in the soil. Carbon dioxide was found to be evolved in greater quantity from soil containing the roots of sorghum than from that containing the roots of corn. Thus, it would seem that the injurious after-effects of sorghum could not be ascribed to an inherent toxicity possessed by sorghum roots in relation to the oxidation of organic matter by soil organisms. That the residues of sorghum destroy the organisms of the soil that oxidize organic matter does not appear tenable since certain of them have been found by Gray and Thornton (3) to oxidize such aromatic compounds as phenol and naphthalene.

To what extent the results of the present investigation may be applied to field soils is a matter of conjecture since the conditions under which these studies were made may be regarded as ideal for the proper development of those phenomena which have been reported. Reactions which occurred in the laboratory within the course of a few days may require as many weeks, or months, to occur under normal field conditions. The extent to which these reactions are operative in soil during the period when plants withdraw the greater portion of their nitrogen probably determines the degree of injury that the growth of sorghum exerts on a succeeding crop.

SUMMARY

Soil cultures containing the ground roots of corn or sorghum were compared with respect to their ability to cause nitrate nitrogen to disappear in soil. The roots were employed in equal quantities by weight and by soluble-organic-matter content. Sorghum roots were found to cause a more rapid disappearance of supplied nitrates than did corn roots.

An organism, designated as "guttation," which is known to assimilate both nitrate nitrogen and carbohydrates, increased in numbers, as revealed by plate counts, less rapidly in soil cultures containing the roots of corn than in those containing the roots of sorghum. It is assumed that other organisms which oxidize organic substances will react toward these residues as did "guttation."

The evolution of carbon dioxide from cultural flasks was more rapid from soil containing sorghum roots than from soil containing

corn roots. This was interpreted as indicating that the organic matter of sorghum roots is more easily oxidized than is that of corn roots.

The results of the investigation suggest that the injurious after-effects of sorghum may be associated with the comparative ease with which its roots are oxidized in soil. This process, which is accompanied with an increase in the number of soil organisms and an increase in the assimilation of nitrate nitrogen, would tend to deplete the soil of available nitrogen. The extent to which these processes are operative in soil when young plants are in need of nitrogen may determine the amount of injury which the sorghum crop exerts on those crops which follow.

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FERTILIZERS FOR FIBER FLAX[1]

W. L. Powers[2]

The value of fiber flax (*Linum usitatissimum* L) varies greatly with the length. The object of this study has been to determine the possibilities of increasing the length and value of fiber flax with the aid of fertilizers or with supplemental irrigation.

In a preceding article (5)[3] the value of the potassium ion in causing stem elongation with alfalfa seedlings was reported. That full returns may not be realized from potassium unless adequate nitrate be present to accompany the cation into the plant roots has been shown by Gericke (4) and by the writer (6). Russell (8) cited experiments by the Irish Department of Agriculture, indicating that flax responds to potassic fertilizer, while phosphate tends to encourage weed growth. Bradbury (2) seems to find that fairly constant moisture and nutrient supply are necessary for uniform rapid development of flax fiber for yield and quality. He reports that lime is occasionally useful as a developer of nutrients in heavy soils, and advises generous manurial treatment of the soil earlier in the crop rotation with stable manure that is free from weed seed.

Nitrate is reported to help start the flax, potassic salts to be used with fair success, and phosphatic fertilizers to produce a coarser straw but of less relative fiber yield. Experiments at the Flax Experiment Station of Selby, England, are cited in which most decisive results were obtained from nitrate, giving an increase each year. Potassium was helpful but less necessary for the heavy textured soils in that region. Experiments by the Department of Agriculture and Textile Industry in Ireland, however, are cited to show that while nitrates are remunerative, much better results have been obtained from potassium salts. Usually the combination of potassium and nitrate was most profitable. The average yield of scutched flax from two trials and of dry retted straw from seven farms was greatest when treated with 150 pounds an acre of muriate of potash. Use of potassium and light applications of ammonium sulfate there seemed to improve the fiber: So, variations in results were found, according to soils. Turner (9) reports that flax does not respond to a large nitrate supply.

Garner, *et al* (3) established the fact that carbohydrate formation is influenced by duration of daily light period which affects the

[1]Contributions from the Soil Department, Oregon Agricultural Experiment Station, Corvallis, Ore. Published with the approval of the Director. Received for publication May 12, 1928.

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[3]Reference by number is to "Literature Cited," p. 763.

acidity relation and probably the water content of the plant tissues. Upward elongation of the vegetative stems was found to give characteristic response to a relatively long daily illumination period, associated with progressive increase in active acidity of the plants, particularly in the region of the growing points. Short day lengths seem to limit height and hasten bloom, simple carbohydrates, moisture, and acidity changes being among the earliest observable responses to modified length of day. In summer radish, elongation of stems from exposure to long day lengths was associated with increase in reducing sugar in the tissues, with the maximum in the upper part of the stem.

Redington and Priestly (7) found maximum production of fiber in plants given 16 hours day length.

Aldaba (1) made an interesting study of structure and development of the cell wall in a bast fiber of Boehmeria (a tropical fiber plant of the nettle family) and fiber flax. He reports that fibers of Boehmeria may attain a length of more than 550 mm, but seems to find that cell enlargements and wall differentiation occur simultaneously, suggesting transformation, the cell wall being formed by a series of telescopic, open, tubular, translucid membranes which gradually change to cell wall lamellae. The elongating apical part of growing fibers is reported to be vested in a slim tubular, colorless membrane which is in direct continuity with the outermost lamellae of the thick wall which is the basal portion of the fiber. The unmodified, clear membranes resemble plasma membranes; react similarly to stains and during plasmolysis; are in direct contact with the protoplasm, but thickening portions are separated from it by one or more subsequently formed layers. In flax fiber the initial telescoping membranes originate at the basal extremity, and later ones at various levels where restrictions occur. These terminate in the basal wall of the compartment. The upper end of the successive telescoping membrane seems perforated so that the growing tip is in direct contact with the protoplasm, while the basal thickening portion is separated from it by one or more subsequently formed layers. The outermost lamella does not become similarly thickened.

EXPERIMENTAL

Flax was grown in water cultures, soil plats, and field fertilizer trials with a view to obtaining information as to the nutritive requirements of this plant for maximum fiber production.

In a fertilizer experiment with 1/10th acre plats, using Wapato silty clay loam at the Oregon Agricultural Experiment Station, yields of flax straw and seed were obtained as reported in Table 1.

TABLE 1.—*Yields of fiber flax and of seed in fertilizer trials on Wapato silty clay loam, Corvallis, Oregon, 1927.*

Treatment	Pounds per acre	Flax yield per acre: Total, *Pounds*	Straw, *Pounds*	Straw, percentage of whole
Untreated	—	2,240	1,760	79
Nitrate of soda	100	2,400	2,000	83
Superphosphate (acid phosphate)	200	2,560	1,920	75
Potassium sulfate	100	2,320	1,920	83
Nitrate and potash	100 each	2,720	1,920	71
Untreated	—	2,560	1,600	63
Potash, super	100 each	2,160	1,680	78
5-7-8[a]	100	1,680	1,200	71
5-7-8	200	1,600	1,200	75
5-7-8	300	2,560	1,600	63
5-7-8	400	1,920	1,520	79
Untreated	—	2,320	1,328	57

[a]Nitrogen, phosphorus, and potassium, respectively.

Table 1, is arranged to show the treatment, total yield in pounds, yield of straw in pounds, and percentage of straw fiber flax. While dry weather interfered somewhat with the yield of the crop in this experiment, which was seeded below an irrigation system the completion of which was delayed too long to provide needed moisture, yet the trial gives indication of the value of potassium sulfate for inducing increased fiber yields, particularly when used in conjunction with nitrate. The effect of nitrate on vegetative growth is marked.

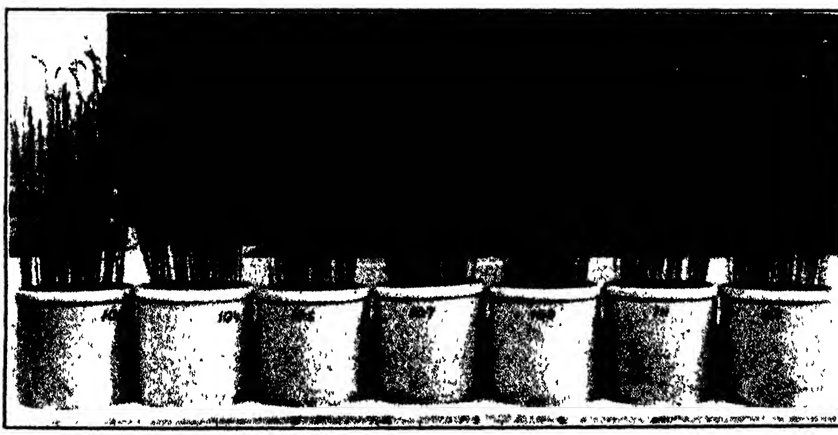

FIG. 1.—Fiber flax pot culture containing Willamette silty clay loam re-enforced with different fertilizers. Left to right: (101) Untreated, (104) sodium nitrate, (105) calcium acid phosphate, (107) potassium sulfate, (109) potassium nitrate, (111) potassium and phosphate, (114) nitrate, phosphate, and potassium.

Nitrate may increase fiber yield less than it does straw yield, and potassium may affect fiber production more. There is also an indication that superphosphate (acid phosphate) is effective in increasing the seed yield, while potassium sulfate increases the ratio of fiber to that of seed. Effect of potassic salts on length of straw is shown in Fig. 1.

A second field fertilizer trial was conducted on Willamette silty clay loam, Monmouth, Oregon, with the results as reported in Table 2.

TABLE 2.—*Yield, height, and quality of fiber flax in fertilizer trials on Willamette silt loam, Monmouth, Oregon, 1927.*

Treatment	Pounds per acre	Yield per acre *Pounds*	Height *Cm*	Comparative quality of fiber	Notes
None	—	4,200	55	11	Nearly ripe
Nitrate of soda	100	4,640	61	3	Tall weeds
Superphosphate (acid phosphate)	200	3,920	55	5	Short weeds
Potassium sulfate	100	4,000	66	4	—
Nitrate and potash	100 each	4,800	69	1	Tallest plants
None	—	4,600	65	7	Ripe
Potash and superphosphate	100 each	4,480	58	8	—
6–7–8[a]	100	4,640	55	6	Very ripe
6–7–8	200	3,520	55	10	Very ripe
6–7–8	300	3,520	61	2	Very ripe
None	—	3,360	54	9	Very ripe

Tensile strength (average of 10 tests, 6 strands each)

Plat 5 Potassium nitrate 42.4 oz. 21% gain over check
Plat 6 Untreated 35.0 oz.

[a]Nitrogen phosphorus, and potassium, respectively.

A maximum yield of flax was secured with potassium and nitrate. This also gave the maximum height or length of straw. This straw was judged by Supt. Fitzgerald, of the Oregon Linen Mills, who has had 20 years' experience in the flax industry and who placed the retted, scutched fiber from the plat receiving potassium nitrate as first in relative quality, not knowing the treatment under which the various samples submitted for judging had been produced.

The textile strength of 10 tests of 6 strands each tested as far as possible according to controlled conditions as prescribed by Professor Edgar H. Barker, of the Lowell, Mass., Textile School, indicated that potassium nitrate increased the textile strength. The fiber was tested after exposure for an hour in a room with the temperature at 70° F and a relative humidity of about 70. It was tested on yarn testers and it was necessary to use 6 strands each 6 inches in length.

The mean breaking strength for the flax from the untreated plat was 35 ounces and for the potassium nitrate plat 42.4 ounces, or a gain of 21%.

Fiber flax was grown in 14 4-gallon stoneware jars, arranged in duplicate series and containing in each case 20 pounds of Willamette silt loam soil. The height, yield of straw, tensile strength, and quality are summarized in Table 3.

TABLE 3.—*Fertilizer experiment with fiber flax in soil culture.*

Pot No.	Treatment and rate per acre, *Pounds*	Mean heigth *Cm*	Mean yield of straw, ave. *Grams*	Tensile strength, of 8 tests, *Ounces*	Comparative quality[a]
1 & 2	None	70	29.5	36	Sixth
3 & 4	$NaNO_3$, 200	78	39.1	38	Fifth
5 & 6	$CaH_4(PO_4)_2$, 200	67	19.5	35	Fourth
7 & 8	K_2SO_4, 200	65	20.8	52	Third
9 & 10	KNO_3, 200	80	41.5	45	First
11 & 12	K_2SO_4, 100; $CaH_4(PO_4)_2$, 100	75	22.8	56	Second
13 & 14	KNO_3, 100; $CaH_4(PO_4)_2$, 100	80	36.8	57	Seventh

[a]Fiber judged by Supt. Jas. J. Fitzsimmons, Oregon Linen Mills.

Planted March 15, 1927; harvested June 25, 1927; 70 days growth period. The duplicates varied 5 to 10% and were bulked for test.

In this trial also further evidence was obtained that potassium used in conjunction with nitrate produces flax of good quality and strength and of superior length. Tensile strength and quality were determined as in the previous experiment.

An experiment was conducted with flax seedlings in water cultures to determine the value of different potassic salts for flax fiber production. Seedlings were grown in potassium-free culture solutions four days, and transferred to single potassium salt solutions at regular intervals for two days. The culture solutions were made up to a total concentration equivalent of about one atmosphere, using mono-

TABLE 4.—*Value of different potassium salts in production of fiber flax.*[a]

Treatment	Mean yield in mgm: Whole culture	Mean yield in mgm: Tops	Mean height, *Cm*
Complete culture solution	1,010	801±.067	21
K-free solution	20	13±.20	2
K-free solution 4 days, $K_2H(PO_4)_2$ 2 days	299	216±.42	20
K-free solution 4 days, KCl 2 days	805	655± 76	25
K-free solution 4 days, K_2SO_4 2 days	1,220	937± 40	28
K-free solution 4 days, KNO_3 2 days	1,884	1,401± 28	34

[a]Set March 15, harvested April 27; 43 days growth period.

FIG. 2.—Fiber flax seedlings grown in solution culture lacking potash transferred to various potash-containing solutions two days in six. Left to right: (1) Without potash, (2) potassium acid sulfate, (3) potassium chlorate, (4) potassium sulfate, (5) potassium nitrate, (6) complete culture solution.

and di-potassium acid phosphate, a saturated solution of calcium sulfate, and magnesium phosphate. Iron was supplied from a fresh solution of ferric tartrate. The mean yields of whole cultures, 30 plants after 43 days growth, period ending April 27, 1927, is presented in Table 4.

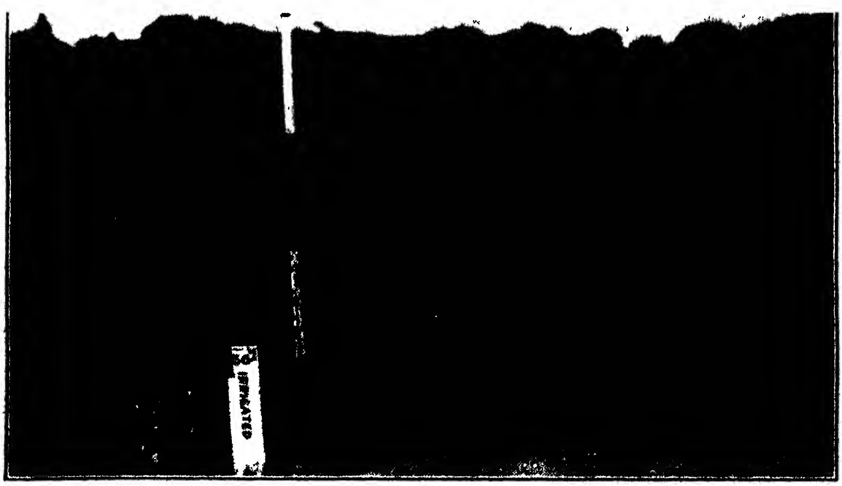

FIG. 3.—Irrigated fiber flax, height 80 cm. Price paid for flax proportional to length.

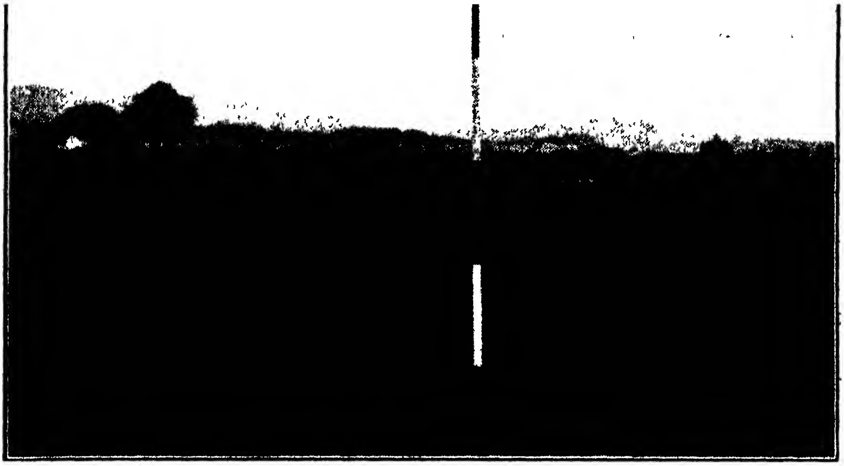

FIG. 4.—Unirrigated fiber flax, height 60 cm.

The mean variation in individual cultures shows a probable error of the order of 3 to 12%, yet differences are as great as 100%. In this controlled experiment the value of potassium nitrate in increasing the length and yield of fiber flax is clearly demonstrated. Potassium salts appeared to make these plants less liable to "wilt." Representative cultures are shown in Fig. 2.

An experiment was arranged to determine the time in the growth period of flax that potassium is most needed. Five 1-gallon stoneware jars were filled with so-called complete culture solutions and 30 flax seedlings set in a perforated veneer cover on each. Another series of jars was prepared with solutions lacking potassium. When the first difference in growth was manifest after two weeks, seedlings from one jar were interchanged with those from a complete solution, after washing the roots of each in pure water. A second pair was interchanged when evidence of potassium starvation appeared a week later. Plants started without potassium failed to overtake in height or vigor those given the reverse treatment, indicating that potassium is especially important early in the growth period of flax.

The value of supplemental irrigation to aid activity of beneficial micro-organisms of the soil and solution of nutrients for plants is illustrated in Figs. 3 and 4. For two seasons irrigation has increased the length of fiber flax 20 cm, and has increased the yield over 50% in connection with these studies. Irrigation may be helpful in retarding ripening so that pulling may be completed before the plants are dead ripe. This should aid in securing a high quality of fiber.

Tall flax is not only more valuable but is more readily harvested, either by hand or with machinery.

DISCUSSION

The potassium ion seems to be an especially important nutrient for fiber flax. It appears to give strength, to increase the length of the fiber, and to render plants more vigorous and disease resistant. This may be due to the action of potassium in keeping lower carbohydrates in solution until they can be translocated to the bast fibers where they are built into tissue. The potassium ion may aid formation of an organic catalyst in carbohydrate synthesis by aiding the formation of an enzyme or co-enzyme. It is suggested that this ion may also be helpful in formation of beet sugar and potato starch. Full returns may not be realized from potassic salts unless nitrates are also present to accompany potassium ion into the plant (6). A little phosphate may be helpful under some conditions as an aid to root development and it should increase yield of seed flax.

The fertilizer requirements of fiber flax may be expected to vary with the soil and its previous cropping and treatments; however, the order of importance of nutrients seems to be potassium first and nitrate second. Nitrate may be more in demand for early vegetative growth and potassium most needed for fiber formation. This point is being investigated further. Fiber flax makes vigorous vegetative growth on muck soil, but the product is low in fiber content. Further studies are under way to test the value of potassic salts for overcoming this deficiency.

Better growth and yield may be expected when flax is planted very early under western Oregon conditions, and provided with a uniform, moderate moisture content. Since flax responds to 16-hour day lengths, as reported by Redington and Priestly (7), it is suggested that the value of early planting here is to secure maximum growth during the longest days of the year, and before the field moisture is depleted. Providing a uniform supply of moisture and nutrient with the aid of supplemental irrigation should increase the length and prevent rapid ripening in order that pulling may be completed before the flax is dead ripe so as to secure a high quality of fiber.

SUMMARY

Potassic salts may be expected to increase length and value of fiber flax. The potassium ion may play a catalytic rôle in synthesis of carbohydrates, or function to keep simpler carbohydrates in solution until they can be deposited in the transforming bast fibers in the flax plant.

Early planting and providing uniform moisture and nutrient supply with the aid of supplemental irrigation in western Oregon tends to delay the maturity and increase the length and value of fiber flax.

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THE CHEMICAL AND PHYSICAL BEHAVIOR OF CERTAIN SYNTHETIC FERTILIZER SALTS WHEN MIXED WITH LIMESTONE AND DOLOMITE[1]

W. H. MacIntire and K. B. Sanders[2]

There are obvious advantages in the use of ground limestone along with concentrated fertilizer materials such as "Nitrophoska" and similar products. The mixing of the two products facilitates uniform drilling. It also minimizes the danger to seed germination by reducing salt concentration. The joint use of the two materials also provides fresh supplies of calcium to effect neutralization of biologically engendered acids and to lessen the production of acidoids, or acid-reacting silicates, in the soil. When dolomitic limestone is used there is the additional advantage of insuring increased supplies of both calcium and magnesium for plant use. Although there seemed to be no valid reason why the materials should not be mixed immediately before incorporation in the soil, it did not follow that the mixtures could be kept for any length of time without detriment, especially in humid seasons. It was necessary to ascertain what effect storage would have upon loss of ammonia, solubility of any component, and mechanical condition.

CHEMICAL STABILITY OF LIMESTONE AND MANURE-SALTS MIXTURES

A study was made to determine the effects of limestone and dolomite upon the stability of five ammoniates, *viz.*, ammonium sulfate, leunasalpeter, potassium-ammonium nitrate, floranid, and nitrophoska. If the limestone were to cause no appreciable evolution of ammonia, other components would be expected to suffer no material chemical change.

AIR-DRY MIXTURES

The first series was made up of air-dry materials. A 20-gram charge of each manurial salt and an 80-gram charge of 100-mesh limestone were introduced into a 500-cc rubber-stoppered Ehrlenmeyer flask and thoroughly mixed. The flask was provided with an intake and outlet so that the atmosphere of the flask could be aspirated for analysis. A parallel series was run with a 100-mesh dolomite that had been dried in a coal-dust flame at the producing plant. The two series were aspirated after 1-, 3-, 19-, and 36-day periods. The cumulative data for the volatilized ammonia that was

[1]Contribution from the Department of Chemistry, Tennessee Agricultural Experiment Station, Knoxville, Tenn. Received for publication May 18, 1928.

[2]Soil Chemist and Assistant Soil Chemist, respectively.

obtained by passing the atmosphere of each flask through a definite amount of standard acid are given in Table 1. In 6 of the 10 dry-mixtures there was either no loss or a loss well within analytical error, whereas the four ammonium sulfate and leunasalpeter mixtures gave losses so meager that they could not be detected by the control methods used in fertilizer analyses.

MOIST MIXTURES

In the foregoing series there was very little moisture present, and it was so tightly held by the surfaces as to preclude chemical action. Such an ideal condition would not always obtain. Duplicates of the set-up given in Table 1 were therefore brought to a uniform moisture content of 6% by the use of limestone that had been moistened by the addition of 7.5% of distilled water. This moisture content is far beyond that which would be found in any limestone that had been protected from the weather. A product so moist would be deemed to be in an unsuitable condition for drilling.

The cumulative data for the volatilization of ammonia, as determined by the seven aspirations over the 59-day period, are given in Table 2. Potassium-ammonium nitrate and floranid gave practically no losses. Even the maximum loss of 0.55 pound per ton of

TABLE 1.—*Liberation of NH_3 from dry mixtures of 100-mesh limestone and dolomite and commercial fertilizer salts, 100-gram charges of 20% salts and 80% limestone.*

Material	Milligrams of N liberated after				Total N liberation		
	1 day	3 days	19 days	36 days	Percentage of original salts	Percentage of 1–4 mixture	Pounds per ton of 1–4 mixture
			Limestone Mixture				
Ammonium sulfate....	0.64	1.29	2.38	4.90	0.0245	0.0049	0.098
Leunasalpeter........	0.49	0.93	1.40	2.76	0.0138	0.0028	0.056
Potassium-ammonium nitrate............	0.00	0.00	0.00	0.10	0.0005	0.0001	0.002
Floranid..............	0.00	0.00	0.00	0.00	0.0000	0.0000	0.000
Nitrophoska..........	0.00	0.11	0.11	0.11	0.0005	0.0001	0.002
			Dolomite Mixture				
Ammonium sulfate....	1.36	2.18	3.90	7.05	0.0353	0.0071	0.142
Leunasalpeter.........	0.00	0.11	0.21	1.22	0.0061	0.0012	0.024
Potassium-ammonium nitrate............	0.11	0.11	0.11	0.11	0.0005	0.0001	0.002
Floranid..............	0.00	0.00	0.00	0.00	0.0000	0.0000	0.0000
Nitrophoska..........	0.00	0.00	0.00	0.00	0.0000	0.0000	0.000

TABLE 2.—*Liberation of NH_3 from moist mixtures of 100-mesh limestone and dolomite and commercial fertilizer salts, 100-gram charges, 20% salts and 80% limestone plus 6% moisture.*

Material	Milligrams of N liberated after							Total N liberation		
								Percentage of		Pounds per ton of
	1 day	3 days	10 days	19 days	36 days	45 days	59 days	Original salt	1–4 mixture	1–4 mixture
					Limestone Mixture					
Ammonium sulfate	0.11	0.57	3.01	4.01	7.70	9.42	10.60	0.0530	0.0106	0.212
Leunasalpeter	0.29	0.75	3.72	4.55	6.98	9.77	11.67	0.0584	0.0117	0.234
Potassium-ammonium nitrate	0.00	0.00	0.29	0.57	1.04	1.86	2.15	0.0108	0.0022	0.044
Floranid	0.00	0.00	0.11	0.21	0.21	0.21	0.21	0.0011	0.0002	0.004
Nitrophoska	1.36	2.90	4.80	5.62	10.02	22.30	27.53	0.1377	0.0275	0.550
					Dolomite Mixture[a]					
Ammonium sulfate	2.08	2.36	5.16	5.16	7.05	9.49	11.38	0.0569	0.0114	0.228
Leunasalpeter	2.08	2.90	6.05	7.77	11.81	14.25	15.97	0.0799	0.0160	0.320
Potassium-ammonium nitrate	1.00	1.11	1.58	2.04	2.69	3.15	3.44	0.0172	0.0034	0.068
Floranid	0.00	0.00	0.11	0.21	0.21	0.21	0.21	0.0011	0.0002	0.004
Nitrophoska	2.08	3.45	5.87	6.69	14.68	21.05	25.56	0.1278	0.0256	0.512
					Dolomite Mixture[b]					
				20 days	30 days	48 days	61 days			
Ammonium sulfate	—	—	—	0.47	1.83	2.65	4.19	0.0220	0.0042	0.084
Leunasalpeter	—	—	—	0.64	1.47	2.83	3.83	0.0192	0.0038	0.076
Potassium-ammonium nitrate	—	—	—	0.00	0.00	0.00	0.00	0.0000	0.0000	0.000
Floranid	—	—	—	0.00	0.00	0.00	0.00	0.0000	0.0000	0.000
Nitrophoska	—	—	—	1.90	3.97	6.05	9.20	0.0460	0.0092	0.184

[a]Dolomite that had been dried in a coal-dust flame.
[b]The same dolomite dried in the laboratory.

mix—that which came from the nitrophoska mixture—is only about one-seventh of the analytical tolerance allowed in the control analysis of fertilizers.

It will be noted that the commercial 100-mesh dolomite proved to be about as active as the more soluble limestone. This dolomite is manufactured by the drying of a filtered product in a coal-dust flame which leaves a meager quantity of alkaline carbonates. As a point of academic interest rather than of practical value, a third series was added by the use of the same dolomite after spontaneous drying. In this series the already meager losses of ammonia were still further decreased. This demonstrated the fact that the less soluble dolomite was even less reactive than the limestone.

It may be concluded, therefore, that the mixing of either limestone or dolomitic limestone with these specific ammoniates may be carried out without fear of chemical losses or changes, and, if the volumes of the charges used in these tests may be used as indicative of mechanical effects to be expected in large piles, there is slight probability of caking.

BEHAVIOR OF CONCENTRATES UNDER HUMID CONDITIONS

The tendency of certain of the concentrates to take up so much moisture from the air as to produce a sticky mass, or even to pass into semi-liquid state, has been a handicap to their use. In some of the more recent concentrates this disadvantage has been lessened by the combination of two or more salts. The technical aspects of the taking up of moisture have been discussed in a recent paper by Ross and Mertz,[3] and also by Wheeler.[4]

CONCENTRATES ALONE

The five materials studied in the ammonia-loss experiments were tested as to their behavior in moist air. A 2-gram charge of each material was introduced into a weighing bottle, and the unstoppered bottle placed under a bell jar, into which was passed a current of air that had been drawn through a column of water. The bottles were removed, stoppered, and weighed after periods of 5, 7, 16, and 30 days. There were moisture increases (Table 3) of only 2.15% and 4.14% for floranid and ammonium sulfate, respectively, but even these increases converted the mechanical condition of the materials from "good" to "caked." The other three salts—nitrophoska, leunasalpeter, and potassium-ammonium nitrate—took up 25.5, 30.3, and 36.97%, respectively, and they were all converted to a semi-liquid state. The speed of the absorption of moisture is shown in Fig. 1.

[3]American Fertilizer, 68: No. 3.
[4]American Fertilizer, 65: No. 2.

TABLE 3.—*Deliquescence of commercial fertilizer salts after continuous exposure to moist atmosphere.*

Material	Physical condition		Moisture absorbed after							
	Initial	After 30 days	5 days		7 days		16 days		30 days	
			Grams	%	*Grams*	%	*Grams*	%	*Grams*	%
Ammonium sulfate[a]	Good	Caked	0.0053	0.27	0.0225	1.13	—	—	0.0828	4.14
Leunasalpeter[b]	Good	Semi-liquid	0.0518	2.59	0.0957	4.79	0.3140	15.70	0.6060	30.30
Potassium-ammonium nitrate[c]	Fairly good	Semi-liquid	0.0753	3.77	0.1368	6.84	0.4176	20.88	0.7393	36.97
Floranid[d]	Fairly good	Caked	0.0009	0.05	0.0137	0.69	0.0267	1.34	0.0429	2.15
Nitrophoska[e]	Fairly good	Semi-liquid	0.0223	1.12	0.0637	3.19	0.2811	14.06	0.5099	25.50

[a]20.6% N.
[b]26% N, ¼ nitrate N and ¾ ammonium N.
[c]15.5% N, ½ nitrate N and ½ ammonium N.
[d]46% N (Urea. B. A. S. F.)
[e]20% N, 32% P_2O_5, 16% K_2O.

Here again the conditions were even more severe than would be the case ordinarily, but it is obvious that deleterious effects may be anticipated when certain of the synthetic materials come into direct contact with moist atmosphere.

CONCENTRATES WITH LIMESTONE

Since the behavior of the salts toward moist atmosphere is dependent upon crystal arrangement and relationships, it was thought that the mixing of a limestone with a concentrate might produce a protective-coating effect that would greatly diminish the taking up of moisture by the salts. Accordingly, the air-dried mixes, which contained 20 parts of salt and 80 parts of limestone—those used in the ammonia-volatilization studies—were exposed to a circulating moist atmosphere for a period of 27 days. Weighings made after 6-, 16-, and 27-day intervals showed (Table 4) that the addition of both limestone and dolomite prevented the absorption of moisture from the humid atmosphere, and under conditions that were more

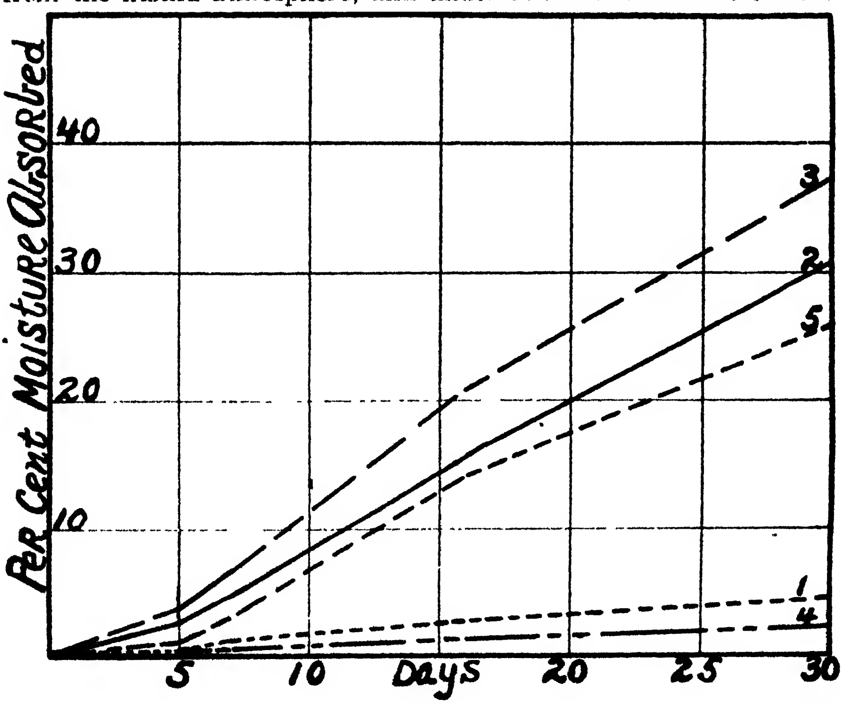

FIG. 1.—Speed of absorption of moisture by five commercial salts when exposed to a circulating moist atmosphere.

1, ammonium sulfate; 2, leunasalpeter; 3, potassium-ammonium nitrate; 4, floranid (urea); and 5, nitrophoska. (No moisture was absorbed by the same salts when they were mixed with limestone and dolomite and exposed under similar conditions.)

TABLE 4.—*Protective action of dry 100-mesh limestone and dolomite against deliquescence of commercial fertilizer salts, 100-gram mixtures containing 20% salts and 80% limestone during continuous exposure to moist atmosphere.*

Material	Total weight of container and mixture: Immediately	After 6 days	After 16 days	After 27 days	Change in final weight: Grams	Percentage of full charge
With Dry Limestone						
Ammonium sulfate	274.5	274.2	274.1	274.1	—0.4	—0.40
Leunasalpeter	277.7	277.5	277.6	277.5	—0.2	—0.20
Potassium-ammonium sulfate	236.0	235.9	236.3	236.3	0.3	0.30
Floranid	250.9	250.7	250.7	250.7	—0.2	—0.20
Nitrophokas	278.8	278.6	278.6	278.0	—0.8	—0.80
With Dry Dolomite						
Ammonium sulfate	283.2	282.9	282.8	282.8	0.6	0.60
Leunasalpeter	284.3	284.2	284.1	284.3	0	0
Potassium-ammonium sulfate	289.7	289.3	289.5	289.9	0.2	0.20
Floranid	270.1	270.0	270.0	270.1	0	0
Nitrophoska	253.1	253.1	253.1	253.1	0	0

extreme than those to be expected in practise. Each mixture also retained the same desirable physical condition that had prevailed at the beginning of the exposure. A mixture of two parts of ground limestone and one of nitrophoska was also exposed for several weeks to the moist atmosphere of a greenhouse and no caking occurred.

SUMMARY

Air-dry mixtures of limestone and dolomite with each of five concentrated synthetic ammoniates showed either no loss of ammonia or the most meager quantities after standing for 36 days at room temperature.

When the same mixtures were brought to a moisture content of 6% the ammonia losses were nil in two cases and measurable in three. The maximum loss, however, was only one-seventh of the analytical error permitted the fertilizer analyst. The absence of any material loss of ammonia established the fact that no change in chemical solubility ensued when the limestone was added to the manurial salts. Natural dolomitic limestone was less reactive than limestone.

The physical condition of each concentrate was affected unfavorably by exposure to a circulating moist atmosphere, and in three cases the salts were practically liquified. This tendency was entirely eliminated when the concentrates were mixed with either of the two limestones in the proportion of one of salt to four of limestone. In a greenhouse experiment a mixture of two parts of nitrophoska and one of ground limestone remained for weeks in a granular and uncaked condition.

A NEW SYSTEM FOR VARIETY TEST PLATS[1]

E. J. DELWICHE[2]

Many agronomists believe that cultivated alleys between plats are a source of error. The differences in plat yields arising from contiguity to an alley are greater with long and narrow plats than with short ones. This is so obvious that it scarcely needs any explanation. On the other hand, the long plat has been proved most satisfactory because of affording a better sample of varying soil conditions than a plat which approaches the square shape.

In variety testing of cereal crops, the alley should be of sufficient width to permit of harvesting with the grain binder without mixing. Consequently, a very narrow alley cannot be used if strains are to be kept pure. In addition there is a difference in the feeding power of different varieties. For these reasons alleys between plats should be fairly wide, not less than 3 feet and preferably 4 feet. The alley itself should be planted in order to utilize plant food and moisture. Planting to another cereal crop has been tried, but this is not satisfactory because of possible mixing and of border effect, owing to relative differences in feeding power for two different grain crops.

In an effort to overcome these difficulties, at least in part, the plan outlined below was tried, under the writer's direction, at four of the Wisconsin branch experiment stations, *viz.*, Ashland, Spooner, Marshfield, and Sturgeon Bay.

As illustrated in Fig. 1, plats were laid to measure ¼ rod x 20 rods, after ends and alleys were cut out, the area to be 1/32 acre. The machine used was a single-disk drill, sowing 16 rows 6 inches apart. An 8-row drill has also been used which requires one round of the drill per plat instead of one-half.

Fig. 1 explains the method of planting. Note that one full plat and the halves of two alleys were sown at once. The fourth and ninth feed spouts were plugged up in order to leave a blank row on each side of the plat in which to run the grain binder point when harvesting.

Fig. 2 is a photograph of the alley taken when the grain was about 6 inches high.

Fig. 3 shows a section of a variety plat of oats at harvest time. In this case four rows were planted in the alley and two left blank. One full plat and one-half of each alley was planted in one-half round of the drill, all sown to one variety.

[1]Contribution from Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wis. Received for publication May 10, 1928

[2]Professor of Agronomy, in charge of Branch Experiment Stations.

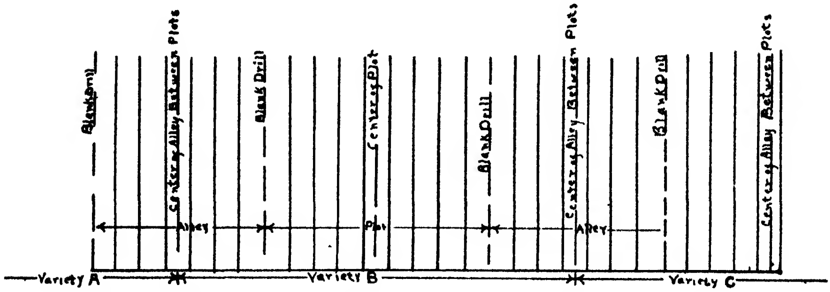

FIG. 1.—Diagram of system of variety test plats with alleys between plats sown to the same varieties as adjacent plats.

FIG. 2.—Showing the alley when the grain was about 6 inches high.

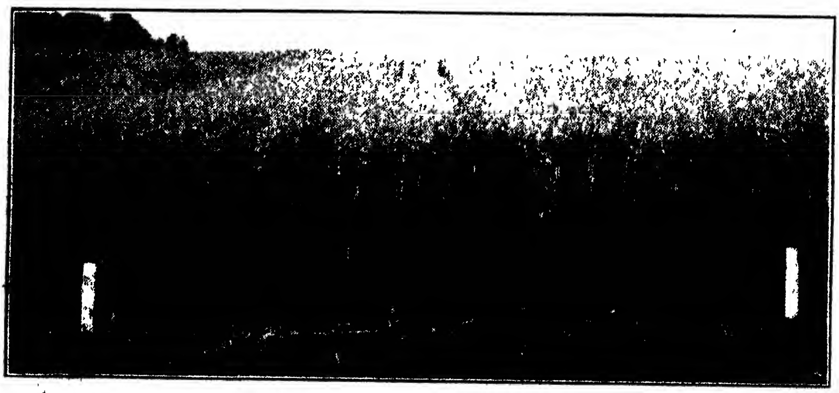

FIG. 3.—A section of a variety plat of oats at harvest time.

SUMMARY

The system of variety platting described above has the following advantages:

1. All operations of planting are done by the use of horse-drawn machinery.
2. It is just as expeditious in execution as the blank alley system.
3. It uses up all of the alley avoiding weeds or the necessity of cultivations.
4. It gets around the border effect due to competition between two unlike varieties by having two or more rows of a given variety on the adjoining alleys.
5. It reduces the danger of mixing since the margin of the plat adjoins the same variety in the alley.
6. It reduces the possibility of exaggerated acre yields since the alley grows a crop of grain similar to that on the plats on each side of it.
7. It permits of the use of long and narrow plats.
8. It does away with the hand labor necessary to remove border rows, a process found necessary by many workers for good results with wide blank alleys between plats.

The only disadvantage is that the system requires somewhat more land than where no crop is grown in the alley between plats. The system has worked out very satisfactorily in tests at four stations and with three kinds of grain. It would be desirable to have the method tried elsewhere, and if possible compare its efficiency with other methods.

NOTE

POLYEMBRYONY IN RICE

Polyembryony in rice is not common. Kuwada[1] shows in Fig. B, *a*, what he called an "abnormal formation of two embryo sac mother cells." The formation of two embryo sac mother cells in this manner suggests the possibility of polyembryony in rice. Komura[2] reports a rice seed which upon germination produced two plumules. Rodrigo[3] found one seed of the rice variety Inintiw that produced two plumules and two primary radicles, one for each plumule. He later germinated about 107,000 seeds of the Inintiw variety and a like number of the Tiniaong variety. In the latter variety there was one seed which produced two plumules, whereas none of the Inintiw seed produced more than one plumule. He concludes that these data indicate that polyembryony is rare in rice.

In a cross of the rice varieties Yosemite and Nimai Kawa Mochi made at Shafter, Calif., in 1926, one seed was obtained that produced two hybrid seedlings. The crossed seeds were sown separately in small paper pots and all operations were carefully performed and checked. When the two plumules were first observed the soil was carefully removed from above the seed and it was found that the two seedlings came from one seed. The two hybrid seedlings when transplanted to the nursery were separated by a marker so that each seedling could be kept under observation. The two hybrid seedlings in the first-, second-, and third-leaf stages were identical in size and appearance. Each of the seedlings had six tillers on July 8, all of which had made a similar growth. The two plants appeared to be identically alike during the entire growing season, except that one matured 15 panicles and the other 16. Both plants were unmistakably hybrids.

After harvest the two hybrid plants were dug up and the soil was carefully washed from the roots. The husk of only one seed was found. It was not possible to determine whether there was more than one primary root. The two hybrid plants apparently were "identical twins" derived from one fertilized egg.—JENKIN W. JONES, *Agronomist, U. S. Department of Agriculture, and Superintendent, Biggs Rice Field Station, Biggs, California.*

[1]KUWADA, Y. A cytological study of *Oryza sativa* L. Bot. Mag. [Tokyo], 24: 267–281, pls. 1–8, figs. 1–2. 1910.

[2]KOMURA, H. A polyembryonal plant of *Oryza sativa* L. Bot. Mag. [Tokyo], 36:23–24, pl. 1. 1922.

[3]RODRIGO, P. A. A case of polyembryony in rice. Philippine Agr., 14:629–630, pl. 1. 1926.

AGRONOMIC AFFAIRS

NEWS ITEMS

W. H. LEONARD, formerly Assistant Extension Agronomist at the Colorado Agricultural Experiment Station, has accepted a two-year fellowship in crops in the Department of Agronomy, University of Nebraska.

A. S. LAIRD, Assistant Agronomist at the Florida Agricultural Experiment Station, resigned June 15 to accept a position with the Office of Forage Crops, U. S. Department of Agriculture, and is stationed at the South Carolina Sand Hill Experiment Station at Pontiac, S. C.

O. T. BONNETT, of the Department of Agronomy, University of Wyoming, has resigned to accept an assistantship and complete his advanced work in plant breeding at the University of Illinois.

J. STEWART WIANT of Cornell University has been appointed to the Department of Agronomy, University of Wyoming, to do research work in plant pathology.

R. J. GARBER, Head of the Department of Agronomy and Genetics at West Virginia University, gave two lectures at the eighth Annual Convention of the Canadian Society of Technical Agriculturists which was held in Quebec, June 11 to 14, inclusive. The subjects of the lectures were "Breeding for Disease Resistance with Particular Reference to the Smut of Oats" and "The Nature and Significance of Mutations in Present-day Breeding Methods."

E. G. BOOTH, Field Agent in Agronomy in the Extension Division of the North Dakota Agricultural College, was granted the Ph.D. degree in Agronomy by the University of Minnesota on June 11. Dr. Booth presented a thesis upon the subject "The Daily Growth of the Oat Kernel and the Effect of Immaturity and Controlled Freezing Temperatures on Germination."

GUSTAV GEISZLER, of Ashley, North Dakota, a 1928 graduate of the North Dakota Agricultural College, has been appointed Assistant in Field Husbandry at the University of Saskatchewan, Saskatoon, Sask.

H. R. ANGELL, who completed work for the doctorate in plant pathology at the University of Wisconsin in June, 1928, has been appointed Extension Plant Pathologist in the Virginia Agricultural Experiment Station for the summer of 1928 until September 15. Dr. Angell replaces S. B. Fenne who resigned June 15, 1928, to become Agricultural County Agent for Washington County, Virginia.

GEORGE F. SPRAGUE, Junior Agronomist in the Office of Cereal Crops and Diseases of the U. S. Bureau of Plant Industry, in charge of cooperative cereal breeding at the North Platte Substation, North Platte, Nebraska, who has been on leave of absence without pay in order to pursue graduate studies in plant breeding at Cornell University during the past two academic years, resumed his work with the U. S. Department of Agriculture on May 22.

KARL S. QUISENBERRY, Associate Agronomist in Western Wheat Investigations, Office of Cereal Crops and Diseases, U. S. Bureau of Plant Industry, will take temporary charge of the cooperative breeding of wheat for rust resistance at the Minnesota Agricultural Experiment Station, University Farm, St. Paul, following the resignation of Dr. O. S. Aamodt, as noted in the June issue of this JOURNAL. He probably will remain there until the summer of 1929.

THOMAS R. STANTON, Agronomist in charge of Oat Investigations, Office of Cereal Crops and Diseases, U. S. Bureau of Plant Industry, has been given leave of absence without pay for one year, effective July 16, in order to take up graduate studies in plant breeding and plant physiology at Cornell University.

K. H. KLAGES, Assistant Agronomist, Oklahoma Agricultural Experiment Station, has resigned his position to accept an appointment as Associate Agronomist at the South Dakota Agricultural Experiment Station and Associate Professor of Agronomy in South Dakota State College, effective August 1.

THE DEGREE of Doctor of Philosophy in Agronomy was conferred in June on the following graduate students in Agronomy at the University of Illinois: E. A. Hollowell, Crop Production; Earl G. Sieveking, Soil Fertility; O. H. Sears, Soil Fertility; and F. L. Winter, Plant Breeding. The Agronomy Department at the University of Illinois has acquired 80 acres of additional land adjacent to the South Farm on the south. It is proposed to devote this land largely to projects concerning corn borer control from the Agronomic standpoint.

G. H. CUTLER, Professor and Assistant Chief of the Department of Agronomy, Purdue University, was granted the degree of doctor of philosophy at the recent commencement exercises of the University of Wisconsin.

HERBERT A. LUNT, formerly Assistant in Soils at the Illinois Agricultural Experiment Station, has been appointed Assistant in Soils at the Connecticut Agricultural Experiment Station, to make special investigations in Forest Soils. He will assume his new duties on the completion of his graduate studies at the University of Illinois, about August first.

CORRECTION BY GEORGE ROBERTS

On Page 1043 of the November, 1927 number of this JOURNAL the statement is made, "Ten tons of manure on the first of the two tobacco crops has increased the yield 93 pounds per acre, etc."

The statement should be: Ten tons of manure on each of the two tobacco crops has increased the yield 93 pounds per acre. The effect of the manure on the second crop was more than two and one-half times greater than its effect on the first crop.

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SYMPOSIUM ON "SOIL SOLUTION"

Leader: G. J. BOUYOUCOS, Michigan State College

1. The Soil Solution from the Physiological Standpoint. B. M. Duggar, University of Wisconsin. (By title only)
2. The Effect of Soil Type and Fertilization on the Composition of the Expressed Sap of Plants. M. M. McCool, Michigan State College.
3. The Relation Between the Total Chemical Composition of the Soil and the Water Extract. W. O. Robinson, Bureau of Chemistry and Soils, U. S. Department of Agriculture.
4. Some Effects of Fertilizers on the Nature of the Soil Solution with Special Reference to Phosphorus. C. H. Spurway, Michigan State College.
5. Plant Composition as a Guide to the Availability of Soil Nutrients. Robt. M. Salter and J. W. Ames, Ohio Agricultural Experiment Station.

1. THE SOIL SOLUTION FROM THE PHYSIOLOGICAL STANDPOINT

B. M. DUGGAR

(By title only)

2. THE EFFECT OF SOIL TYPE AND FERTILIZATION ON THE COMPOSITION OF THE EXPRESSED SAP OF PLANTS[1]

M. M. McCool and M. D. Weldon[2]

It is obvious that plants are materially affected by the nature of the soil in which they grow. It is well known that crops grown under similar climatic conditions on different soil types vary not only with respect to yield but also in quality or flavor, color, nutritive value, and other qualities. Farmers may be found who recognize some pastures to be more nutritious than others, and the hay from certain fields to be more valuable for feed than that from other fields. The so-called malnutrition of animals is reported to be rather local in occurrence, and appears to be correlated with certain soil types. Yet it seems that more information on the relationships between soil type and plant is needed.

When attempts are made to follow up the soil surveys with experiments on soil types to determine their crop adaptations and fertilizer requirements, and to ascertain whether or not the soil types may be grouped with respect to their requirements for satisfactory crop production, some interesting problems arise. This is to be expected, especially if cognizance is taken of the complexity of soils, and also of the fact that we are dealing with biological processes in such undertakings.

Early in the work in Michigan we met up with some things which were not as might have been predicted. The following questions have arisen in connection with our investigations: Are the amounts of each of the several mineral plant nutrients in circulation or in the juice of a given crop grown on different soils similar or widely different? Do the amounts vary in juice from different parts of the same plant? Does there appear to be a minimum amount of each nutrient for proper plant growth? To what extent, if any, does the application of fertilizers to the soil affect these relationships? Is there any relation between the soil reaction and the calcium content of the juice? These questions, together with the development of microchemical tests and their use in the study of the soil solution led us to take up a study of the amount of certain elements in the expressed sap of crops grown under widely different soil conditions. Some

[1]Paper read as part of the symposium on "Soil Solution" at the meeting of the Society held in Chicago, Ill., Nov. 18, 1927. Contribution from the Soils Department, Michigan State College, East Lansing, Mich.

[2]Professor of Soils and Research Assistant in Soils, respectively.

of the results obtained thus far appear to be noteworthy and will be presented briefly.

This work was begun in the spring of 1926. During the growing season of that year many determinations of the phosphorus content of the juice of several crops were made. Striking differences were found in the amount present in various crops, as well as in the same crop grown under different soil conditions. Reference to these results is made in a previous publication (5)[3] in which the following statement is made: "It may be that a phosphorus deficiency in the soil may be detected by cell sap studies of crops grown on it." Part of a paper (6) prepared for the meetings of the First International Soil Science Congress in Washington deals with the phosphorus and potassium content of the juice of certain crops.

Recent studies by Gilbert and Hardin (3) of the Rhode Island Experiment Station are summarized as follows: "In general the current concentrations of mineral nutrients in the solutions of crop plants were found to correlate directly with applications of chemical fertilizers. Potassium was found to show the least fluctuation during the season; nitrate nitrogen fluctuated the most, while the fluctuation of phosphate phosphorus was intermediate. The current mineral nutrient content of the plant solution is suggested as an index of fertilizer needs, and tentative critical concentrations have been chosen for each nutrient."

METHODS OF PROCEDURE

In our preliminary work it was attempted to determine the phosphorus present in the form of phosphate by pressing the sample in a small hand press and testing a few drops of the juice so obtained with the reagent described by Spurway (7). While this method readily indicates large differences in phosphate content, it was found that the chlorophyll present obscures the color reaction and makes it impossible to distinguish small differences. The method was, therefore, discarded.

The work has now been extended to include the determinations of nitrate nitrogen, phosphorus, potassium, calcium, and magnesium. The material to be analyzed is ground in a food chopper, placed in a steel cylinder of 9 cm diameter, having a close-fitting piston, and subjected to a pressure of 1 ton. Wrapping the ground sample in a single layer of cheesecloth facilitates the escape of the juice.

For the nitrate determination, a portion of the juice is treated with lead subacetate solution and centrifuged to remove chlorophyll

[3]Reference by number is to "Literature Cited," page 791.

and other organic materials. The supernatant liquid is poured off, shaken with "Norit" carbon black, and filtered. The filtrate is heated in a water bath with excess of calcium hydrate, magnesium carbonate, silver sulfate solution, and copper sulfate solution, and filtered. This procedure is sufficient to remove all organic matter and chlorides. Portions of the filtrate are evaporated to dryness on a steam bath and nitrate nitrogen is determined by the usual phenol-disulfonic acid method.

For the determinations of phosphorus, potassium, calcium, and magnesium, a portion of the juice is centrifuged and about 15 grams of the liquid dried and ignited in a crucible at barely red heat. The ash is taken up in 5 to 10 cc of 6 N hydrochloric acid and made up to 100 cc. Phosphate is determined by the colorimetric method described by Atkins (2), potassium by the volumetric method of Adie and Wood (1), calcium by the usual volumetric method, and magnesium by the volumetric method of Handy (4).

PLAN OF GREENHOUSE EXPERIMENTS

Greenhouse work to determine the effect of fertilizer treatments on the composition of the juice was begun in 1926. In one set of tests, plants were grown in 2-gallon glazed earthenware pots; in another set, flat boxes measuring 1 by 2 feet and 3½ inches deep were used. A rather raw muck soil, slightly acid in reaction, was used for both phosphate and potash treatments. A Hillsdale loam, which responds well to phosphate, and a Coloma sand were selected for phosphate and potash treatments, respectively. For the phosphate treatments, each soil was well supplied with urea and potassium chloride, and for

TABLE 1.—*Phosphorus content of the juice of barley 36 days after planting.*

Soil	Treatment			
	Monocalcium phosphate, grams	Potassium chloride, grams	Weight of 24 plants, grams	Phosphorus in juice, %
Muck	0	2	14.6	0.0030
	2.5	2	24.5	0.0100
	2.5	2	41.2	0.0190
Hillsdale loam	0	2	22.4	0.0029
	0.5	2	22.5	0.0051
	2.5	2	26.9	0.0059
Muck	2	0	31.3	0.0140
	2	1.5	37.1	0.0153
	2	7.5	34.5	0.0201
Coloma sand	5	0	25.6	0.0178
	5	1.5	27.0	0.0200
	5	7.5	21.2	0.0235

the potash treatments with urea and monocalcium phosphate. The moisture content was maintained near the optimum. Barley, sugar beets, and field beans were grown in both pots and flats and red clover in pots.

This work included only phosphorus and potassium determinations. Table 1 shows the phosphorus content of the juice of the barley plants grown for 36 days in flats on soils variously treated. The phosphorus content increased not only with the amount of phosphate applied, but also with the amount of potash applied. This was the case only in young, rapidly growing plants; in older plants, the application of potash had a tendency to decrease the phosphorus content. This is illustrated in Table 2 which gives the analysis of plants from the same flats at 90 days of age.

TABLE 2.—*Phosphorus content of the juice of barley 90 days after planting.*

Soil	Treatment			Phosphorus in juice of	
	Monocalcium phosphate, grams	Potassium chloride, grams	Weight of 24 plants, grams	Leaves %	Stems %
Muck	0	2	18.0	0.0020	
	0.5	2	52.1	0.0064	0.0104
	2.5	2	68.7	0.0360	0.0310
Hillsdale loam	0	2	84.3	0.0083	0.0089
	0.5	2	91.7	0.0099	0.0129
	2.5	2	75.2	0.0137	0.0177
Muck	2	0	57.7	0.0556	0.0777
	2	1.5	85.3	0.0318	0.0212
	2	7.5	49.6	0.0342	0.0170
Coloma sand	5	0	59.3	0.0423	0.0216
	5	1.5	46.6	0.0284	0.0216
	5	7.5	53.7	0.0271	0.0204

The phosphorus content of the plants on muck soil which received no phosphate was very low throughout the life of the plants. These plants made almost no growth after five weeks from planting, while those receiving adequate phosphate fertilizer grew rapidly and maintained a much higher concentration of phosphorus in the juice. It is obvious that on the muck which received no phosphate this element was the limiting factor.

All of the plants on Hillsdale soil remained vigorous and healthy and made about as much growth as the best treatment on muck. The phosphorus content of the sap was much lower than that of the best plants on muck. Applications of phosphate on Hillsdale loam produced much less response, both in the growth of the plant and in the phosphorus content of the juice, than similar applications on

muck. The mineral soil appeared to absorb phosphate more actively than the muck and to maintain a low but sufficient concentration throughout the growing period.

TABLE 3.—*Potassium content of the juice of barley 36 days after planting.*

Soil	Treatment: Monocalcium phosphate, grams	Treatment: Potassium chloride, grams	Weight of 24 plants, grams	Potassium in juice of above-ground parts, %
Muck	0	2	14.6	0.390
	0.5	2	24.5	0.355
	2.5	2	41.2	0.242
Hillsadale loam	0	2	22.4	0.394
	0.5	2	22.5	0.362
	2.5	2	26.9	0.322
Muck	2	0	31.3	0.068
	2	1.5	37.1	0.174
	2	7.5	34.5	0.204
Coloma sand	5	0	25.6	0.257
	5	1.5	27.0	0.392
	5	7.5	21.2	0.522

TABLE 4.—*Potassium content of the juice of barley 90 days after planting.*

Soil	Treatment: Monocalcium phosphate, grams	Treatment: Potassium chloride, grams	Weight of 24 plants, grams	Potassium in juice of Leaves %	Potassium in juice of Stems %
Muck	0	2	18.0	1.24	
	0.5	2	52.1	0.73	0.80
	2.5	2	68.7	0.60	0.77
Hillsdale loam	0	2	84 3	——	0.60
	0.5	2	91.7	0.40	0.62
	2.5	2	75.2	0.40	0.58
Muck	2	0	57.7	0.31	0.26
	2	1.5	85.3	0.56	0.54
	2	7.5	49.6	0.86	0.60
Coloma sand	5	0	59.3	0.46	0.26
	5	1.5	46.6	0.37	0.46
	5	7.5	53.7	0.39	0.62

Tables 3 and 4 show the potassium content of the same samples given in Tables 1 and 2. The potassium content of the juice 36 days after planting paralleled the potash applied as fertilizer. The phosphate fertilizer decreased the potassium content in young, rapidly growing plants. It is probable that the potassium supplied to the roots within a limited volume of soil remained constant. A

rapidly growing plant would, therefore, contain a lower percentage of potassium than a slowly growing one. This is further indicated by comparing the potassium content of older plants, as shown in Table 4. On the muck which received no phosphate, the plants made practically no growth and their juice contained much potassium. On the Hillsdale soil the no-phosphate plants made nearly as much growth as the others and contained no more potassium.

Table 5 shows results from red clover grown on muck in pots. Samples were taken 82 days after planting. Clover showed a great response to both phosphate and potash. The amount of each element in the juice is roughly proportional to the amount applied. Each fertilizer showed a tendency to decrease the amount of the other in the juice of the crop. Here again the amount of potash available to the plants was probably about the same in each of the first five pots, regardless of the amount of growth made by each plant, so that slow-

TABLE 5.—*Phosphorus and potassium content of the juice of red clover on muck 82 days after planting.*

Treatment				
Monocalcium phosphate, mgm	Potassium chloride, mgm	Weight of 2 plants, grams	Phosphorus in juice %	Potassium in juice %
0	200	6.2	0.0077	0.192
50	200	7.5	0.0103	0.234
100	200	13.0	0.0096	0.232
300	200	27.3	0.0135	0.091
600	200	31.7	0.0212	0.045
300	0	15.7	0.0159	0.044
300	25	20.8	0.0130	0.045
300	75	26.5	0.0140	0.042
300	400	38.8	0.0082	0.078
300	600	25.0	0.0105	0.151

TABLE 6.—*Phosphorus and potassium content of the juice of field beans on muck 56 days after planting.*

Sample No.	Treatment		Weight of 4 plants, grams	Phosphorus in juice %	Potassium in juice %
	Monocalcium phosphate, mgm	Potassium chloride, mgm			
1	0	200	17.5	0.0035	—
2	50	200	31.5	0.0049	0.106
3	100	200	38.5	0.0068	0.086
4	300	200	48.0	0.0108	0.165
6	300	0	42.4	0.0141	0.034
7	300	25	31.7	0.0177	0.028
8	300	75	41.6	0.0157	0.048
9	300	400	47.9	0.0147	0.123
10	300	600	57.4	0.0113	0.200

growing plants were able to concentrate their supply of potash in a smaller amount of juice. The same explanation may be offered in the case of phosphorus in the last five pots.

The results with field beans grown on muck in pots are indicated in Table 6. The application of each fertilizer element increased the amount of that element in the juice. The effect of the rate of growth on the accumulation of phosphorus is shown in samples 6 to 10.. The plants making the least growth, sample 7, contained the largest percentage of phosphorus; the plants making the greatest growth, samole 10, contained the least phosphorus; while the other three samples were similar in rate of growth and in phosphorus content.

FIELD PLAT INVESTIGATIONS

Field sam les of celery and cabbage on muck soil were taken during the fa l of 1926. Phosphorus and potassium were determined in the juice of these crops. The results for celery are given in Table 7.

TABLE 7.—*Phosphorus and potassium in the juice of leaves and stalks of celery grown in field plats on muck.*

Fertilizer applied in pounds per acre: Ammonium sulfate	20% super-phosphate	Potassium chloride	Phosphorus in juice of: Leaves %	Stalks %	Potassium in juice of: Leaves %	Stalks %
0	0	500	0.0094	0.0060	0.305	0.360
0	750	500	0.0125	0.0118	0.360	0.352
0	750	750	0.0170	0.0109	0.375	0.408
0	500	0	0.0179	0.0228	0.239	0.255
0	0	0	0.0088	0.0080	0.327	0.260
300	500	500	0.0218	0.0118	0.418	0.392

The amount of each of these elements found in the juice correlated with the amount applied as fertilizer. This was especially the case with phosphorus. Plants on plats receiving no phosphorus were decidedly low in that element. This was true to a somewhat lesser degree for potassium. Some mutual effect of the two elements on each other can be observed. Potassium appeared to increase the phosphorus content of the leaves and decrease that of the stalks. For example, of the plants receiving no phosphate, those receiving no potash contained 0.0088 and 0.0080 % of phosphorus in the leaves and stalks, respectively. Similar effects were obtained in plants receiving 500 or 750 pounds of phosphate per acre.

The phosphorus content of the sap in the leaves was higher than that in the stalks, with one exception in the case of the plat receiving

phosphate alone. The potassium content was about equal in leaves and stalks.

Table 8 shows the analysis of the juice of leaves and midribs of cabbage grown on a similar series of plats. The application of 500 pounds of superphosphate increased the phosphorus content of the juice, but 750 pounds produced no additional increase. The potassium content likewise showed a marked response to 500 pounds of potash, with little further effect from 750 pounds. It also tended to be slightly higher in the leaves than in the midribs. The phosphorus content was considerably higher in the midribs. Neither element exhibited any effect on the other.

On September 30, 1927, samples were taken of leaves and stems of sugar beets grown on muck soil in field plats. The phosphorus and potassium contents of the juice are shown in Table 9. Applications of phosphorus fertilizer had a tendency to increase the concentration of that element in the juice. The samples from the plat receiving both phosphate and potash contained no more phosphorus than those from the check plat, but considerably more than those from the second check plat. Samples from the plat receiving potash and phosphate showed less phosphorus than those receiving phosphate alone, but this decrease was probably due, at least in part, to the difference in the soil of the two plats. The difference between the two check plats and the general trend of the figures indicate that the soil varied more or less regularly from one end of the field to the other in its capacity to supply the crop with mineral nutrients. The applications of potash fertilizer produced a marked increase in the potassium content of the juice, especially when used alone. The effect of superphosphate in increasing the phosphorus content was less marked, but its effect in decreasing the potassium content was clearly in evidence. With one exception, the concentration of both elements in the leaves was greater than that in the stems.

TABLE 8.—*Phosphorus and potassium in the juice of leaves and midribs of cabbage grown in field plats on muck.*

Fertilizer applied in pounds per acre			Phosphorus in juice of		Potassium in juice of	
Ammonium sulfate	20% super-phosphate	Potassium chloride	Leaves	Midribs	Leaves	Midribs
			%	%	%	%
0	0	500	0.0063	0.0034	0.236	0.227
0	750	500	0.0091	0.0055	0.244	0.238
0	750	750	0.0094	0.0062	——	0.256
0	500	0	0.0108	0.0068	0.122	0.119
0	0	0	0.0064	0.0032	0.128	0.116
300	500	500	0.0102	0.0102	0.221	0.315

TABLE 9.—*Phosphorus and potassium in the juice of leaves and stems of sugar beets in field plats on muck, Sept. 30, 1927.*

Fertilizer applied in pounds per acre		Phosphorus in juice of		Potassium in juice of	
20% super-phosphate	Potassium chloride	Leaves %	Stems %	Leaves %	Stems %
0	0	0.0198	0.0072	0.194	0.108
300	0	0.0224	0.0115	0.097	0.034
300	300	0.0197	0.0071	0.340	0.251
0	300	0.0143	0.0045	0.343	0.345
0	0	0.0124	0.0044	0.108	0.078

Calcium and magnesium were determined in these samples. Practically no calcium was found (less than 0.001 %), but an appreciable amount of magnesium (0.01 to 0.07%) was present. The magnesium content of the sap was in every case greater in the leaves than in the stems. The magnesium content was greater on the check plats than on the fertilized plats.

TABLE 10.—*Phosphorus and potassium in the juice of sugar beets on Miami loam, Oct. 12, 1927.*

Fertilizer applied in pounds per acre		Phosphorus in juice of		Potassium in juice of		Magnesium in juice of	
20% super-phosphate	Potassium chloride	Leaves %	Stems %	Leaves %	Stems %	Leaves %	Stems %
0	100	0.0105	0.0069	0.298	0.353	0.12	0.12
200	100	0.0126	0.0085	0.285	0.370	0.08	0.12
400	100	0.0161	0.0140	0.336	0.414	0.20	0.11
800	100	0.0217	0.0202	0.225	0.294	0.15	0.13
400	0	0.0233	0.0207	0.186	0.190	0.16	0.07
400	50	0.0222	0.0162	0.224	0.313	0.11	0.07
400	200	0.0193	0.0164	0.195	0.280	0.14	0.10

TABLE 11.—*Phosphorus and potassium in the juice of sugar beets on Berrien sandy loam, Oct. 22, 1927.*

Fertilizer applied in pounds per acre		Phosphorus in juice of		Potassium in juice of	
20% super-phosphate	Potassium chloride	Leaves %	Stems %	Leaves %	Stems %
0	0	0.0196	0.0080	0.336	0.288
0	100	0.0178	0.0074	0.328	0.276
200	100	0.0254	0.0103	0.409	0.342
400	100	0.0337	0.0153	0.399	0.344
800	100	0.0265	0.0098	0.344	0.314
400	0	0.251	0.0242	0.420	0.338
400	50	0.0338	0.0197	0.516	0.404
400	200	0.0306	0.0178	0.322	0.411

On October 12, 1927, samples of sugar beet leaves and stems were taken from plats on Miami loam.[4] On October 22, samples were taken from plats on Berrien sandy loam. The results are set forth in Tables 10 and 11. The potash fertilizer showed a tendency to decrease the phosphorus content. The superphosphate produced the same effect on potassium content. The phosphorus content of the juice was in every case higher in the leaves than in the stems. In the case of potassium, the leaves contained more than the stems on the Berrien soil, while the reverse was true on the Miami soil. The explanation for this probably lies in the fact that the Miami samples were taken during a period of rainy weather. These were the only samples taken under such conditions, and they were the only samples in which the potassium content of the leaves was consistently lower than that of the stems. These facts indicate that a considerable amount of potassium can be washed from the tissues by water. The stems present a relatively small surface area to the leaching action of rains, and, therefore, suffer less loss of soluble salts.

These samples contained no calcium. The magnesium content was usually higher in the leaves than in the stems and was apparently not correlated with the fertilizer applications.

Table 12 shows the phosphorus and potassium content of the juice of winter wheat in field plats. The fertilizers used were ammonium sulfate, triple superphosphate, and potassium chloride. Each

TABLE 12.—*Phosphorus and potassium content of the juice of wheat grown on Hillsdale loam, Nov. 15, 1927.*

Fertilizer applied[a]	Phosphorus in juice of tops %	Potassium in juice of tops %
N P K	0.0535	0.584
N P	0.0527	0.471
N K	0.0476	0.756
Check	0.0406	0.600
Lime alone	0.0352	0.373
N	0.0376	0.598
K	0.0426	0.588
P	0.0559	0.672
Lime alone	0.0464	0.638
P K	0.0810	0.793

[a]Nitrogen (N) was applied as ammonium sulfate, phosphorus (P) as triple superphosphate, and potassium (K) in the form of chloride. All plats were limed except the check.

[4]Data obtained subsequent to the presentation of this paper at the meeting of the Society have been incorporated in the published article to make the record as complete as possible.

one was applied to all the plats indicated at the same rate. All plats except the check were limed. Samples from the plats which received superphosphate all showed increased concentrations of phosphorus in the juice in comparison with those receiving no phosphate. Yields of wheat on these plats respond well to superphosphate.

The results given in Table 13 are typical of those obtained from wheat samples grown in field plats on Hillsdale sandy loam. Considering first the nitrate nitrogen of the sap, it will be observed that on those plats receiving potash fertilizer the nitrate content was low, even lower than on the check and lime plats. On plats receiving phosphate the nitrate content was high. Ammonium sulfate had a tendency to increase the nitrate content, but its effect was much less marked than that of the phosphate.

TABLE 13.—*Analysis of the juice of wheat samples grown on Hillsdale sandy loam, Nov. 29, 1927.*

Fertilizer applied[a]	Nitrate nitrogen, p.p.m.	Phosphorus %	Potassium %	Calcium %	Magnesium %
N P K	19.8	0.0786	0.655	0.075	0.027
N P	43.1	0.0915	0.585	0.091	0.040
N K	23.7	0.0629	0.710	0.075	0.053
Check	—	0.0663	0.542	0.088	0.050
Lime alone	21.8	0.0742	0.570	0.099	0.049
N	37.1	0.0538	0.537	0.068	0.072
K	14.0	0.0589	0.575	0.087	0.083
P	57.5	0.0844	0.590	0.092	0.107
Check	23.0	0.0597	0.614	0.074	0.105
Lime alone	20.6	0.0740	0.560	0.106	0.038
P K	14.4	0.1250	0.618	0.074	0.075

[a]Nitrogen (N) was applied as ammonium sulfate, phosphorus (P) as triple superphosphate, and potassium (K) in the form of chloride. All plats were limed except the checks.

The phosphorus content of the juice was highest on the plats receiving phosphate. It was lower on the check plats than on the limed plats. The use of potash fertilizer was reflected in the potassium content of the juice. This effect was not as consistent as in the case of phosphorus, but the potash-treated plats averaged considerably higher than those receiving no potash. Wheat from the plats receiving lime alone contained more calcium than the checks. There appeared to be no significant differences in the calcium content due to other treatments, nor was the magnesium content correlated with the fertilizer applications.

It is interesting to note that in 1927 the yields of wheat on this series of plats showed the greatest increase from applications of

phosphate and the least from potash, while nitrogen was intermediate in effectiveness. The use of lime alone produced a marked increase in yield.

Samples of rye growing on Coloma sand were taken on November 30, 1927. The analyses are shown in Table 14. The phosphorus content was lowest on the check plat, highest on the lime-and-phosphate plat, and intermediate on the plat which received lime alone. The potassium content was highest on the check and lowest on the phosphate plat.

Table 15 gives the analysis of wheat samples grown on Fox sandy loam and taken on December 1, 1927. The nitrate content of the sap was lowest on the check and lime plats. Successive increases were produced by applications of superphosphate, superphosphate and potash, and ammonium sulfate, superphosphate, and potash in addition to the lime. The high phosphorus content on the check plat was probably due to the very slow rate of growth on this plat in comparison with the others. The yield of wheat on the check plat in 1927 was less than one-third of that on any of the other plats.

TABLE 14.—*Analysis of the juice of rye samples on Coloma sand, Nov. 30, 1927.*

Fertilizer applied	Phosphorus %	Potassium %	Calcium %	Magnesium %
Check	0.082	0.579	0.055	0.061
Lime	0.101	0.523	0.059	0.014
Lime and phosphate	0.112	0.454	0.052	0.088

TABLE 15.—*Analysis of the juice of wheat samples on Fox sandy loam, Dec. 1, 1927.*

Fertilizer applied	Nitrate nitrogen, p.p.m.	Phosphorus %	Potassium %	Calcium %	Magnesium %
Check	37.6	0.1230	0.356	0.049	0.089
Lime, NPK	123.0	0.0849	0.411	0.043	0.039
Lime, PK	73.6	0.0870	0.450	0.051	0.054
Lime, P	58.7	0.0816	0.316	0.051	0.062
Lime, alone	52.2	0.0621	0.519	0.035	0.057

The fact is well known, and is illustrated by some of the data presented here, that the first increment of fertilizer applied produces the greatest effect on the growth of the plant. The beneficial effect of successive increments becomes less and less until a maximum growth is obtained. Beyond this point, additional increments of fertilizer are detrimental to the plant. If we plat the amount of fertilizer applied against the weight of the crop, we obtain a graph similar to (a) in Fig. I, which shows the effect of applications of monocalcium phosphate on the growth of field beans on muck soil in greenhouse pots. The percentage of phosphorus in the sap, represented by (b),

also increases rapidly and appears to be very nearly a linear function of the amount of fertilizer applied. When we investigate the water-soluble phosphorus in the soil, however, we find that our present methods can detect none in the unfertilized soil or in the soil which has received small applications. Water-soluble phosphorus appears when larger applications are made and the greater the application, the greater its effect on the water-soluble material, as shown by the increasing slope of the graph (c) in Fig. I. It appears that the plant is

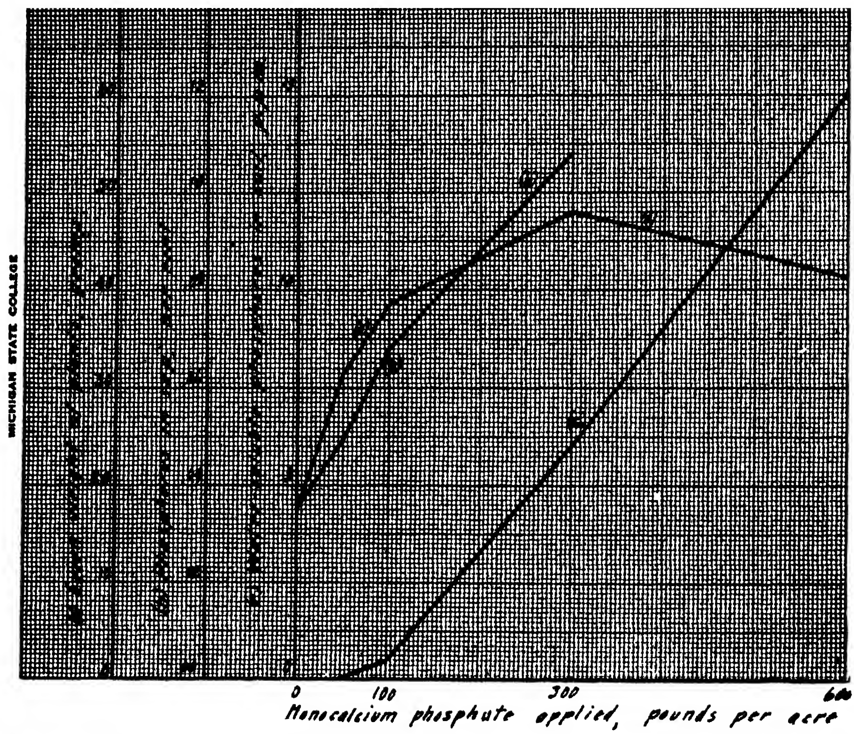

FIG. 1.—Graph showing the effect of applications of monocalcium phosphate fertilizer on the growth of the plant, the amount of phosphorus in the sap, and the water-soluble phosphorus in the soil.

able in some cases to take in phosphorus from a soil which contains none in a water-soluble condition, so far as we are able to detect by methods which will indicate the presence of as little as 0.02 part of phosphorus per million of solution. Furthermore, addition of phosphate fertilizer to the soil may stimulate the growth of the plant to a remarkable extent and increase the phosphorus content of its juice without increasing the water-soluble phosphorus to the point where it may be detected. Before maximum growth is obtained, however,

phosphorus appears in the soil extract in appreciable quantities, usually within the range of 1 to 10 p. p. m. This seems to be the case with most of the common field crops in both muck and mineral soils, both in the greenhouse and in the field.

The graphs in Fig. I were drawn from the data presented in Table 16.

TABLE 16.—*Field beans grown on muck in greenhouse pots.*

Monocalcium phosphate in pounds per acre	Green weight of plants, grams	Phosphorus in juice %	Water-soluble phosphorus in soil, p.p.m.
0	17.5	0.0035	0
50	31.5	0.0049	0
100	38.5	0.0068	0.5
300	48.0	0.0108	6.0
600	40.7	———	15.0

SUMMARY

Greenhouse samples of barley, sugar beets, field beans, and red clover, and field samples of celery, cabbage, sugar beets, wheat, and rye have been studied as to the content of certain mineral nutrients in the expressed juice.

Field samples generally contain more of these nutrients than greenhouse samples.

The percentage of each nutrient in the juice of the leaves is usually greater than in that of the stems, but in rainy weather potassium may be leached from the leaves to a greater extent than from the stems.

Applications of the various mineral nutrients to the soil as fertilizer generally result in increased concentrations of those elements in the juice of the crop.

If one element is decidedly a limiting factor, the slow growth of the plant appears to permit the accumulation of high concentrations of other elements. Under these conditions, applications of the limiting element to the soil as fertilizer are likely to decrease the concentrations of the other elements in the plant.

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3. THE RELATION BETWEEN THE TOTAL CHEMICAL COMPOSITION OF THE SOIL AND THE WATER EXTRACT[1]

W. O. Robinson[2]

There have been few contributions dealing directly with the relation of the composition of the soil to the water extract, possibly because such a relation would hardly be expected, but chiefly because the object of most investigations dealing with water extracts has been to correlate the results with soil productivity rather than with the total composition of the soil.

DISCUSSION OF ANALYTICAL DATA AVAILABLE

Analyses of the water extracts of soils have been frequently reported; but in comparatively few cases have the total analyses of the soil been given, so comparisons can be made in relatively few instances. In these few cases there is the further complication that the extracts were often made under widely different conditions—the ratio of water to soil, the temperature, the time of contact, agitation, presence or absence of carbon dioxide, all have varied.

The early work of Grouven (8)[3], Peters (14), Schultze (15), and others was reviewed by King (12) in 1905. From a consideration of this earlier work and his own data, King established several important points.

The first point established was that a highly productive soil yields a water extract high in the soluble mineral elements, whereas an extract from a poor soil is lower. The productive soils used were the Janesville, Miami, and Hagerstown loams, and the poor soils were Norfolk sand, Selma silt loam, and Sassafras sandy loam. The analysis of the sample of Janesville loam shows it to be well supplied with the plant food elements. Numerous analyses of the members of the Miami and Hagerstown series show them to be likewise well supplied. The Norfolk, Sassafras, and Selma series, however, are very low in plant food. There is, then, in these soils, which represent extremes of composition, a relation between the total and water-soluble constituents.

The second point established by King in his elaborate successive leaching experiments was that the quantities of silica, potash, and

[1]Paper read as part of the symposium on "Soil Solution" at the meeting of the Society held in Chicago, Ill., Nov. 18, 1927. Contribution from the Bureau of Soils and Chemistry, U. S. Dept. of Agriculture, Washington, D. C.

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[3]Reference by number is to "Literature Cited," page 800.

magnesia were about constant in 11 successive leachings. The sulfates, chlorides, and nitrates were almost completely extracted in from six to seven leachings and lime was reduced to one-fourth its original quantity in the last leaching. The phosphoric acid increased in the later washings apparently with the decrease in lime. These successive leaching experiments show that quite different extracts may be obtained from the same soil according to conditions of rainfall and drought immediately preceding the taking of the sample from the field. Obviously, there can be no set relation between the total and water soluble constituents when the samples are taken under different conditions of leaching.

Kelley and McGeorge (11) have presented considerable data for Hawaiian soils. In the case of 12 soils where the water extract was made under comparable conditions there was some relation between the total and water-soluble calcium, but there was no obvious relation in the case of the other constituents. The water-soluble phosphoric acid, for instance, did not vary much, but there was great variation in the total phosphorus.

Hall, Brenchley, and Underwood (9), on comparing the water extracts and the drainage waters of some of the Rothamsted experimental plats with the total composition of the soil, found that there was no relation between the total composition and the water extract, but that there was a significant relation between the fertilizer treatment and the composition of the water extract and drainage water. Plats that had been fertilized with potash yielded an extract high in potash. Mitscherlich (13), using carbonated water as a solvent, was able to distinguish between fertilized and unfertilized soils.

Bouyoucos (3) found that productive soils gave extracts high in total soluble matter and unproductive soils gave extracts low in soluble matter. From analyses that have been made of the soils which he used (Norfolk sand and Carrington and Marshall loams) it seems that there was some general relation between the total and water-soluble constituents in these soils of extreme composition. Some of the solubility experiments ran for 65 days. Most of the soils reached an apparent equilibrium in six to eight days. The soils did not show a true solubility, however, for the solutions obtained by extracting 1 part of soil with 0.7 part of water were roughly twice as concentrated as those of a 1 to 5 extraction.

Hoagland (10), Stewart (16), and Burd (5) showed that the concentration of the soil extract varied considerably during the growing season as the constituents were taken up by plants and as conditions of drought and leaching alternated. They also showed that a soil

once depleted of part of its soluble constituents did not rapidly recover its capacity to furnish soluble salts and that such depletion might last a full season. The phosphoric acid did not vary as did the other elements. It thus seemed to have a true solubility. Wrangell and Haase (17) have also shown this to be true of certain European soils. These results indicate that a close correlation can not be expected between the total and water-soluble constituents.

Unpublished data obtained by Hazen, formerly of the U. S. Bureau of Soils, show a fair correlation between the total and water-soluble calcium and a slight correlation between the total and water-soluble sodium. Soil solution experiments running about four months showed that the soils used, Greenville sand and Hagerstown loam, continued to yield more soluble matter with time, though at a decreasing rate. The increase in total solids in the latter part of the experiment was largely due to calcium and sodium. In the California experiments, Stewart (16) shows that calcium is dissolved from the soil, after cropping, more readily than potassium.

So far as the anions are concerned, there must be a close correlation between the total and water-soluble nitrates, sulfates, and chlorides. Methods of analysis assume this, and successive leaching experiments show that the nitrates, sulfates, and chlorides are removed in a few leachings. Carbonates and bicarbonates are more persistent and phosphates behave quite differently from the other anions. Phosphates are much less soluble, and show a tendency to have a true solubility, hence no correlation would be expected between the total and water-soluble phosphorus.

The above experiments show no obvious dependence of the composition of the soil solution upon the total composition of the soil, except in the case of the more soluble anions and of calcium and of sodium to a less degree. Where the soils are of extreme composition there is some relation between the composition of the solution and that of the soil. For instance, a leached, sandy soil yields an extract low in everything; a soil containing calcium carbonate yields a solution high in calcium; a laterite containing little else than iron and aluminum yields almost nothing. But when soils of less extreme composition are compared, it often happens that a soil high in some particular constituent may yield a solution lower in that constituent than a soil containing a much smaller quantity of the constituent. This discrepancy may be due in part to the different conditions under which the solutions were made. However, the combinations in which the elements are present in soils are so variable in their

behavior toward water that little relation between the total and water soluble parts is to be expected.

EFFECT OF SOIL MINERALS UPON SOIL SOLUTION

The soil is made up of two general kinds of material which behave very differently toward water. They are the undecomposed soil-forming minerals and the clay or colloidal material.

The soil minerals are mainly of igneous origin. Formed at high temperatures and in the absence of water, they are not stable when bathed with water, as they are at most places on the earth's surface; consequently they break down with the formation of a colloidal residue and a solution.

There seems to be some doubt as to whether the reaction between the common soil minerals and water is reversible or not. This is an important point in considering the relation of the composition of the soil to that of the water extract. If the reaction were reversible and the minerals could crystallize from water solution, then there could be no correlation between the composition of the soil and that of the water extract. So long as any mineral remained in the soil, the solution in equilibrium would be constant in composition with regard to that mineral's components, and the ratio of water-soluble to total constituent would thus depend solely upon the quantity of mineral in the soil.

There is no mention in Clarke's "Data of Geochemistry" (6) of the common soil-forming minerals having been made in the wet way at ordinary pressures. They have, however, been made at will by fusion. The evaporation of a soil solution never yields the common soil-forming minerals. At first an amorphous precipitate is formed followed by crystals of the simpler salts, such as sulfates and chlorides of sodium, and later, at high concentration, by double salts. The quantities of silica, iron, and aluminum in solution when the crystalline matter separates out are totally inadequate to form the common soil minerals.

The facts that enormous beds of residual clay result from the decay of rock minerals, that soils much alike in mineral composition give quite different solutions, and that in dry regions soluble salts are found in large quantities leave little doubt that the reaction between water and the common soil minerals, other than quartz, is irreversible.

Granting that the reaction between water and the common soil-forming minerals is irreversible and one of decomposition, it follows that the quantity of soluble matter formed will be dependent upon a great number of factors. If the conditions outside the water-mineral

mixture are kept constant, then the quantity of soluble matter will depend upon the kind and extent of the mineral surface exposed, the protection of the film of colloidal residues, and the capacity of these colloidal residues for adsorption. When these facts are considered, it would seem that there can be little correlation between the total compositions of the soils containing much undecomposed minerals and the water extract of these soils.

Bouyoucos (4) gives the solubility of a number of minerals under different conditions. This work shows, in agreement with fragmentary work of other investigators, that an apparent equilibrium is reached between water and the powdered mineral in a few days. As time goes on there is very little change in the case of most minerals. Some may give a very slight increase and some an actual decrease. This is not true equilibrium, such as would be given by a solution of sodium chloride in water, for the composition of the solution varies with the ratio of water to mineral, except in the case of a very few minerals.

The apparent equilibrium obtaining between mineral powders and water demands an explanation. Cushman and Hubbard (7) have attributed the decrease in the rate of solubility to the formation of a protective film. The composition of the soluble matter obtained in mineral solubility experiments shows that the major part of the iron, alumina, and silica which would result from the decomposition of the mineral is insoluble. These insoluble decomposition products form the protective film. After an apparent equilibrium had been reached between a sample of ground orthoclase and water, Cushman and Hubbard reground the orthoclase and succeeded in extracting considerably more soluble matter. This indicated that an adhering film was arresting the decomposition. They show that the colloidal film has the power to absorb and hold bases and that for this reason the quantity of bases in solution is not a measure of the decomposition of the mineral powder.

Some idea of the relative quantities of soluble and insoluble matter formed by the action of water on mineral powders may be gotten from the following experiment. A water extract of an orthoclase powder contained 84 p. p. m. of potash, 7 p. p. m. of silica, and 3 p. p. m. of alumina. The composition of orthoclase being $KAlSi_3O_8$, it follows that the insoluble part would amount to 413 p. p. m. of alumina and silica. This insoluble material, according to Cushman and Hubbard (7), has a considerable capacity to absorb potassium.

Bouyoucos' (4) work on mineral powders showed that calcite and gypsum, which occur occasionally in soils, have a definite solubility

in water, as would be expected from the fact that crystals of calcite or gypsum can be obtained by evaporating a water solution of their components. The solutions from these minerals were constant in composition, though the ratio of water to mineral varied. Quartz, kaolin, and zircon behaved similarly to the minerals showing a true solubility, but the quantity of soluble matter yielded by these minerals was so low as to be within the limits of experimental error.

The soil minerals differ greatly in their "solubility" or rates of decomposition in water. Among minerals furnishing the same component, such as leucite, glauconite, orthoclase, microcline, and muscovite, there is a great difference in the rate at which potash is given to the solution. Unless it is known in what minerals the total potassium occurs in the soil, a correlation between the total and water-soluble potassium seems out of the question. The same is true of different minerals containing calcium, magnesium, and sodium. Even if the proportions of the various minerals in the soil were known and also their "solubility" in various states of subdivision, the data would be so complicated that it would be almost impossible to calculate the composition of the water extract.

EFFECT OF COLLOIDAL MATTER ON SOIL SOLUTION

It is certain that any solution formed by the action of water upon soil minerals is subject to considerable modification by the colloidal matter. It is well known that the colloid exchanges bases with neutral salt solutions and releases bases to solutions as weakly acid as carbonic acid, if, indeed, it does not exchange hydrogen with such a solution. There is, however, a great difference in the conditions under which base exchange phenomenon have been studied and those obtaining in water extracts of soils. Most work on base exchange has been done with relatively concentrated (from 0.1 to 4 N) single-salt solutions. The extract yielded by a mineral is very dilute in comparison and contains several different cations. However, the facts brought out in studies of base exchange in soils probably apply to the influence of the colloid on the soil solution.

So far as the cations are concerned, the reaction of soil colloidal matter with a salt solution is one of exchange; hence it might be assumed that the colloid has little effect on the total concentration of a soil solution, provided, of course, that hydrogen ions are included as part of the concentration. It is also known that the colloidal materials in soils of humid regions yield surprisingly constant proportions of calcium, magnesium, potassium, and sodium to a neutral salt solution (Anderson and Mattson, 2). The exchanged

solution contains on the average 65 equivalents of calcium, 25 of magnesium, and 5 each of potassium and sodium. These figures would, of course, be different for the colloidal matter of alkali soils. From these facts, it might be expected that the colloidal matter would modify a mineral solution in the direction of the composition just mentioned of the exchanged solution.

For simplicity, the subject thus far has been treated as though the soil extract was the solution yielded by minerals as modified by the colloidal matter. But the reaction between the minerals and the colloids, is, of course, reciprocal; if the colloid alters the composition of the mineral solution, the rate of solubility of the minerals is thereby modified.

The presence of carbon dioxide in the water used in some laboratory experiments and in the field modifies the soil extract to a large degree. In the field, where the carbon dioxide of the soil water is one of the main factors governing the concentration of soil solutions (Mitscherlich, 13), the cations are probably obtained from the colloidal matter rather than from the minerals. The reaction of base exchange is rapid, the greater part of it being practically instantaneous, whereas the reaction with the minerals is slow and must be dependent upon the rate of decomposition of the mineral.

In spite of the obvious complications, it is not improbable that some general relation between the composition of the colloid and the soil solution may be found. Anderson and Mattson (2) have found that there is a relation between the exchangeable bases and the reaction of the solution. Colloids having a high content of exchangeable bases yield an alkaline solution, whereas colloids low in exchangeable bases yield an acid solution. In general, alkaline soil solutions are high in bases, particularly calcium, while acid solutions are low in monovalent and divalent bases. Since it has also been found that the exchangeable bases usually make up about one-third of the total bases, a rough correlation would be expected between the total and water-soluble monovalent and divalent bases of soil colloids.

The organic matter of soils is properly a part of the colloidal matter. It is highly dispersible and appears in the colloidal fractions, from which it cannot be separated mechanically from inorganic material. Pure organic colloids obtained from peat possess a high capacity to adsorb dye, ammonia, and water (Anderson, et al, 1), and presumably the ordinary bases, behaving in this respect much like the inorganic colloids.

There is no obvious reason for any correlation between the total

and water-soluble organic matter. In fact, the accumulation of a large quantity of organic matter would point to its insolubility.

The organic matter has a profound indirect effect on the soil solution by reason of the microbiological activity which it supports. Under anaerobic conditions the quantity of soluble iron and manganese may be several hundred times greater than under aerobic conditions, owing to the production of soluble ferrous and manganous compounds. Probably the most important part played by the organic matter in regulating the soil solution is through the formation of carbon dioxide from it by biological activity. Owing to the increase in the hydrogen-ion concentration of water by virtue of the carbon dioxide dissolved in it, carbonated water is a relatively strong solvent for soils. Presumably a soil well supplied with organic matter will yield carbon dioxide to the soil solution more rapidly than a soil poor in organic matter, other things being equal.

The colloidal matter apparently contains fewer different combinations of the mineral elements than the soil minerals, and its reaction with water and salt solution is quicker. For these reasons there would appear to be a closer relation between the total and water-soluble constituents of pure soil colloids than between the total and water-soluble constituent of soils containing a large quantity of undecomposed minerals. This relation should also hold with soil made up chiefly of the clay fraction, or of clay and pure quartz sand.

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4. SOME EFFECTS OF FERTILIZERS ON THE NATURE OF THE SOIL SOLUTION WITH SPECIAL REFERENCE TO PHOSPHORUS[1]

C. H. SPURWAY[2]

The rate and degree of solubility of a solute in a solvent, or of simple mixtures of solutes and solvents, can be determined quite accurately in most cases; but in the case of soils, the difficulties encountered in removing the solution unaltered from the soil mass greatly interferes with the accuracy of solubility determinations, especially when small quantities of substances are to be determined. Most of the soil studies conducted along this line have been made relative to some empirical method, or deductions have been made by analogy to better known conditions. In soils we find not only a relatively large number of substances dissolving in the soil solution, but the situation is still further complicated by the fact that these several soil substances are combined together in variable systems—both the substance and the system affecting solubility relationships. We are handicapped by the lack of suitable methods for studying the composition of the soil water as it surrounds the soil particles, and which acts as a source of supply of nutrient elements.

The quantity of a nutrient element in solution in the soil water at any one time is the resultant of the several contributing factors, whatever they may be. Some of these factors are known, and it is probable that some are unknown. That the same factors do not influence all the nutrient elements alike can be deducted from the known properties of these elements and these compounds; and because of the dynamic nature of soils, we know that the factors themselves which influence soil solution are constantly changing. The situation, then, with respect to the solubility of a nutrient element applied to the soil in the form of fertilizer, is complex, being influenced by many changing factors.

Some studies have been made on the solubility of phosphorus in soils by means of a simple field test before and after the addition of phosphorus fertilizers.[3] This work is, primarily, an attempt to determine just what can be accomplished in the field by means of a

[1]Paper read as part of the symposium on "Soil Solution" at the meeting of the Society held in Chicago, Ill., Nov. 18, 1927. Contribution from the Soils Department, Michigan State College, East Lansing, Mich.

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[3]SPURWAY, C. H. Test soils for water soluble phosphorus. Mich. Agr. Exp. Sta. Quart. Bul., 9: 64-67. 1926.

TABLE 1.—*Phosphorus tests compared with quantities of fertilizers applied to field soils.*[a]

		A. P.			A. P.				A. P.		
1.	Ck.	250 pounds	17.	Ck.	250 pounds	500 pounds	25.	Ck.	250 pounds	500 pounds	750 pounds
	0.5	1.0		—	—	0.5		—	0.5	0.5	2.0
		Ana.			A. P.				A. P.		
2.	Ck.	84 pounds	18.	Ck.	250 pounds	500 pounds	26.	Ck.	100 pounds	200 pounds	300 pounds
	—	0.5		0.5	1.0	2.0		—	—	—	1.0
		A. P.			Ana.	A. P.			2–16–0		
4.	Ck.	250 pounds	19.	Ck.	100 pounds	200 pounds	27.	Ck.	250 pounds	500 pounds	100 pounds
	+	0.5		0.5	1.0	1.0		—	0.5	0.5	1.0
		A. P.		Peppermint	0–8–0	0–0–24				2–16–6	
7.	Ck.	500 pounds	20.	Ck.	500 pounds	500 pounds	28.	Ck.	250 pounds	500 pounds	1,000 pounds
	0.5	0.5		2.0	3.0	3.0		0.5	0.5	1.0	2.0
		A. P.		Onions	4–4–16	4–8–16			0–0–24	0–8–0	0–8–24
6.	Ck.	250 pounds	21.	Ck.	1,200 pounds	1,200 pounds	29.	Ck.	800 pounds	800 pounds	800 pounds
	0.5	1.0		0.5	2.0	4.0		2.0	2.0	3.0	3.0
		4–8–8			A. P.				A. P.		
15.	Ck.	1.200 pounds	22.	Ck.	250 pounds	500 pounds	30.	Ck.	250 pounds	500 pounds	750 pounds
	2.0	3.0		+	0.5	1.0		—	—	0.5	0.5
		A. P.			A. P.				A. P.		
16.	Ck.	250 pounds	23.	Ck.	200 pounds	300 pounds	31.	Ck.	250 pounds	500 pounds	500 pounds + K
	—	0.5		0.5	1.0	2.0		0.5	0.5	1.0	2.0

[a]A. P. = Acid phosphate. Ana = Anaconda phosphate. Phosphorus in p.p.m. of the soil extracts.

sensitive micro-chemical test when applied to studies of this kind, but the resulting data throw some light on the effects of fertilizers in modifying the concentration of the soil solution.

In general, a rough correlation exists between test results and quantity of fertilizer applied.[4] (See Tables 1 and 2.) Because of the intervention of certain modifying factors, however, one can not expect to find a direct correlation between test results and quantity of phosphorus added to the soil. One of these factors is the growing crop. Some difficulty was experienced in showing test differences between check plats and fertilized plats under a luxuriantly growing crop that covered the ground, particularly on soils that are apparently strong fixers of phosphorus and when relatively small broadcast applications of fertilizer were made. The crop may have taken the phosphorus out of the soil as fast as it became soluble. Sometimes small differences in phosphorus content can be shown by close comparisons—differences that cannot be tabulated by means of the system of notation adopted. Another important factor in this connection is the power of a soil to make the applied phosphorus insoluble. The greater this power, the less soluble is the applied phosphorus. This fixing power of a soil, however, is not always permanent. Some soils are variable in this respect, changing with the conditions that modify soil structure, such as climatic changes, cultural operations, and effects of the fertilizers themselves.

Test results obtained from the use of a micro-chemical test of this kind cannot be correlated directly with crop response to fertilizers except over the range in which the element in question is limiting. If some other element or factor is the limiting one, then the test cannot be used as an indicator of crop response. On the other hand, if for instance relatively high phosphorus tests are obtained, some factor other than phosphorus may be limiting, and if this other limiting factor is corrected, the soil may respond to further additions of phosphorus.

An important matter in studies of this kind is the time and place of taking the soil sample for the testing operation. Soils may vary considerably within short distances in their content of water-soluble phosphorus, and a knowledge of the possibilities for variation in this respect is requisite for good results. It was found that some soils gave higher phosphorus tests when dry than when wet. The drying of the soil, in these cases, caused phosphorus to become soluble, which was thought to be due to changes in the colloidal system in-

[4]Fertilizer and crop yield data were taken from the fertility work of the Soils Department, Michigan State College.

TABLE 2.—*Potato Experiments.*[a]

Onaway			Roselawn			Kewanee		
A. P.[b]	P test	Yield in bushels per acre	A. P.[b]	P test	Yield in bushels per acre	A. P.[b]	P test	Yield in bushels per acre
Check	—	157	Check	—	159	Check	0.5	149
200	0.5	180	200	0.5	161	200	1.0	205
400	1.0	204	400	2.0	192	400	1.0	221
600	1.0	200	600	0.5	170	600	2.0	183
800	2.0	223	800	1.0	173	800	2.0	201

Onaway 2–16–6			Roselawn 2–16–6			Kewanee 2–16–6		
Fertilizer in pounds	P test	Yield in bushels per acre	Fertilizer in pounds	P test	Yield in bushels per acre	Fertilizer in pounds	P test	Yield in bushels per acre
Check	—	147	Check	0.5	37	Check	1.0	111
250	0.5	192	375	0.5	84	250	2.0	106
500	1.0	178	750	1.0	110	500	2.0	114
1,000	3.0	167	1,500	2.0	112	1,000	3.0	138

[a]Phosphorus tests in p.p.m. of soil extracts.
[b]Pounds of acid phosphate + 100 pounds $NaNo_3$ + 100 pounds KCl.

duced by the evaporation of water. It was found, also, that during periods of dry weather more soluble phosphorus could be obtained at the soil surface than in the nearest soil beneath the surface, and that the salt incrustations commonly found on soil surfaces always gave tests for phosphorus. Evidently, at least some of the more soluble soil phosphorus is brought to the surface and deposited there during periods of drying weather, and is dissolved and washed into the soil again by rains. Hence, all of the data presented here were obtained by testing surface samples during dry weather. The water-soluble phosphorus content of soils is influenced by decaying plants, droppings from animals, manure piles, burning of log heaps, forest fires, and as before mentioned, factors that change soil structure. If the testing is to be done after fertilizer applications, the method of applying the fertilizer is important to the manner of taking soil samples for the test. The operator should know, or attempt to discover, if the fertilizer has been broadcasted, drilled in the row or beside the row, or above or below the seed, or checked in hills. A thorough examination of any situation is necessary in order to obtain data that may be interpreted to practical advantage.

The tables show, in the check plat results, the variation found in the soluble phosphorus content of untreated soils. Table 2 shows some correlations between phosphorus test results and potato yields when nitrogen and potassium have been supplied with the phosphorus.

This phosphorus test has been criticized on the basis of not being sensitive enough to show minor variations in soluble phosphorus content, but an examination of the results presented will show that very little additional information can be obtained by a more sensitive field test, while greater sensitivity would increase the hazards of its use.

From the intensive study made by means of the test it is concluded that valuable practical information may be obtained from a systematic use of it. As a general observation soils showing 0.5 p.p.m. or less of soluble phosphorus respond to phosphorus fertilization. On soils showing 2.0 p.p.m. or more, the profitable use of phosphorus fertilizers is doubtful, except perhaps in intensive farming systems where the other nutrient elements are supplied in abundance. The accumulation and removal of soluble phosphorus in soils may be determined by means of the test, and also some indication of the phosphorus-fixing power of the soil. By comparing water-soluble and dilute acid-soluble tests an idea of the quantity of phosphorus in reserve may be obtained—a low water-soluble but high dilute acid-

soluble test indicating reserve phosphorus coming into solution slowly. On the whole, the best practical use of a micro-chemical test for determining concentration of a nutrient element in the soil solution is considered to be one in which the test is applied systematically over a period of time and as a control measure.

5. PLANT COMPOSITION AS A GUIDE TO THE AVAILABILITY OF SOIL NUTRIENTS[1]

ROBT. M. SALTER AND J. W. AMES[2]

That plants show variations in their contents of nitrogen and mineral elements depending upon the character of the soil is well recognized. It was early discovered that these variations correlated with fertilizer treatments and presumably reflected the supply of available constituents in the soil. As early as 1869, Hellriegel (1)[3] discussed the amounts of potash in oats straw as related to the supply in the soil. It was natural that attempts should be made to use plant composition as a guide to manurial practise.

About 1880, Heinrich (2), from analyses of roots of the oat plant, deduced that specific manuring is necessary if the composition falls below certain fixed minima. Many similar attempts to use plant composition as an index of soil requirement might be cited. Reference will be limited to the conclusions of Hall (3), who in 1905, after a study of the composition of crops grown upon the Rothamsted plats and elsewhere, published an article entitled "The Analysis of the Soil by Means of the Plant." He states the problem as follows, "The scheme is to take a particular plant grown upon the soil in question and determine in its ash the proportions of constituents like phosphoric acid and potash. Any deviations from the normal in these proportions may then be taken as indicating deficiency or excess of the same constituent in the soil and therefore the need or otherwise of specific manuring in that direction. The theory rests upon the assumption, first that each plant has a typical ash composition, constant when the plant is grown under similar conditions; secondly that the variations in the proportions of such a constituent as phosphoric acid will reflect the amount of that plant food available in the soil, as measured by the response of the crop to phosphatic manuring."

Table 1 is a reproduction of data cited by Hall and is illustrative of the facts upon which he based his final conclusion that, "Pending the determination of phosphoric acid and potash 'constants' for some test plant occurring naturally on unmanured land, the interpretation of soil conditions from analyses of plant ashes is not a practical method by which chemical analysis of the soil can be displaced."

[1]Paper read as part of the symposium on "Soil Solution" at the meeting of the Society held in Chicago, Ill., Nov. 18, 1927. Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio.

[2]Agronomist and Associate Agronomist, respectively. Credit is due F. A. Welton and A. G. Hartzler for the accumulation of data cited in Tables 8 to 13, inclusive, and in Figs. 4, 5, and 6.

[3]Reference by number is to "Literature Cited," page 834.

TABLE I.—*Broadbalk wheat, 1882-91.*

Plat	Manuring	Potash: In ash of whole plant %	Potash: In soil (1893) Total %	Potash: In soil (1893) Citric acid soluble %
7	Nitrogen, phosphoric acid, potash	27.38	0.262	0.0232
13	Nitrogen, phosphoric acid, potash	25.36	0.273	0.0188
2	Farmyard manure	20.38	0.285	0.0384
5	Phosphoric acid, potash	19.39	0.279	0.0308
14	Nitrogen, phosphoric acid	18.26	0.240	0.0024
12	Nitrogen, phosphoric acid	17.88	0.223	0.0040
3	Unmanured	17.42	0.220	0.0032
10	Nitrogen only	17.27	0.237	0.0036
11	Nitrogen, phosphoric acid	13.80	0.197	0.0032

Hall states that, while the proportion of phosphoric acid and of potash in the ash varies with the supply of these constituents in available form as indicated by crop response, the extent of such variation is limited and is often no greater than the variations due to season, or than the other variations induced by differences in the supply of non-essential ash constituents, such as soda, lime, etc.

These conclusions find support in the fact that the accumulation of many similar data by other workers has, so far, led to the development of no useful method of predicting nutrient requirements from the composition of crops when these are grown to maturity under field conditions where environmental factors are always inconstant and uncontrollable. Doubtless the factors influencing the intake of any given nutrient by a plant are so numerous as to preclude the hope of using plant composition as a guide to soil requirements unless steps are taken either to control or measure the influence of these factors. Before considering some of the methods in which some degree of control has been attempted, it may be well to inquire briefly into the course of the process by which nutrients are assimilated by the plant.

The rate at which common crop plants take up nitrogen, phosphorus, and potassium has been extensively studied. Duley and Miller (4) give a partial review and bibliography of the literature. In addition to researches cited by these authors, attention should be called to the reports of the following German workers: Adorzan (5), Fest (6), Liebscher (7), Remy (8), Pfeiffer, Rippel, and Pfotenhauer (9), v. Sigmond (10), and Schleusner (11). In general, it may be said that the rates at which these nutrient elements are absorbed bear no constant relation to the rate at which the plant increases in dry weight, nutrient absorption being commonly more

rapid during the early stages of growth and slower during the later stages than the total growth rate. This is illustrated by the graphs in Figs. 1 and 2 which show, respectively, the intake of nutrient elements by corn at Wooster in 1926 and similar data for barley reported by Pfeiffer, Rippel, and Pfotenhauer (9). The relative rates of intake

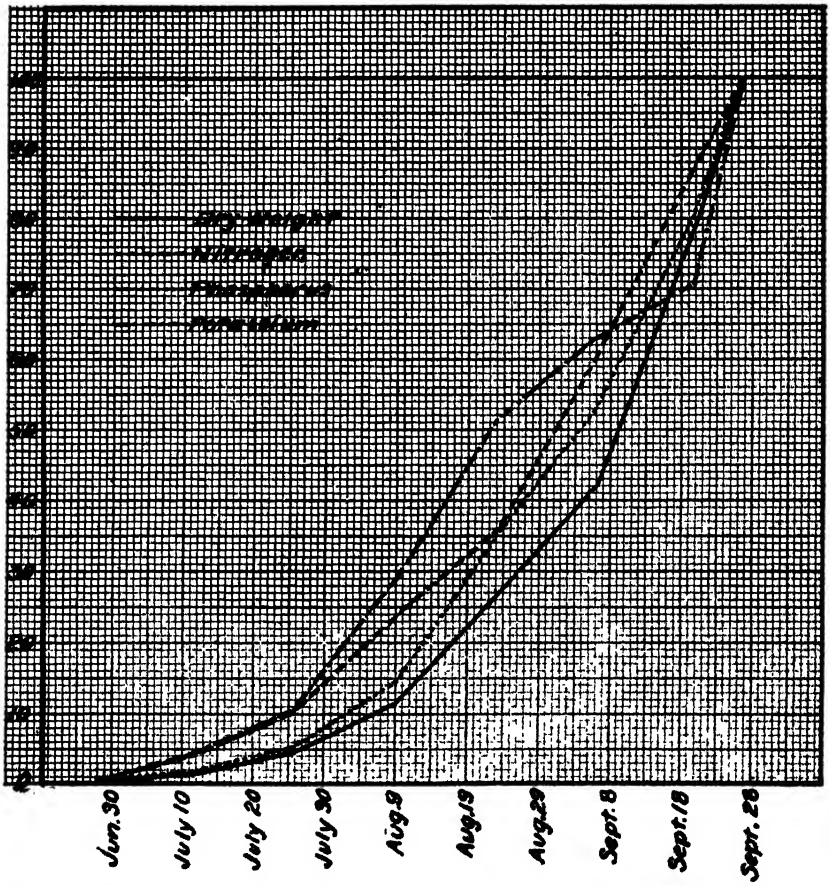

Fig. 1.—Relative dry weight and relative total content of nitrogen, phosphorus, and potassium in corn at Wooster, Ohio, 1927.

for nitrogen and potassium exceed the growth rate in the early stages more than does the rate of intake of phosphorus. This is reflected in higher percentages of nitrogen and potassium in the dry matter of the young plants than are found in the later stages of growth. The percentage composition of the dry substance for the successive growth periods is shown in Table 2.

A frequently observed fact, not indicated by the data cited except the graph showing the total potassium content of barley, is the tendency for a reduction in the total content of nutrient elements in some plants during the later stages of maturity. While there is some evidence that there may be a return of nutrient elements to the soil at these stages, the loss can in most cases be largely attributed to the leaching action of rain, especially upon those parts of the plants which lose their moisture and cease to function.

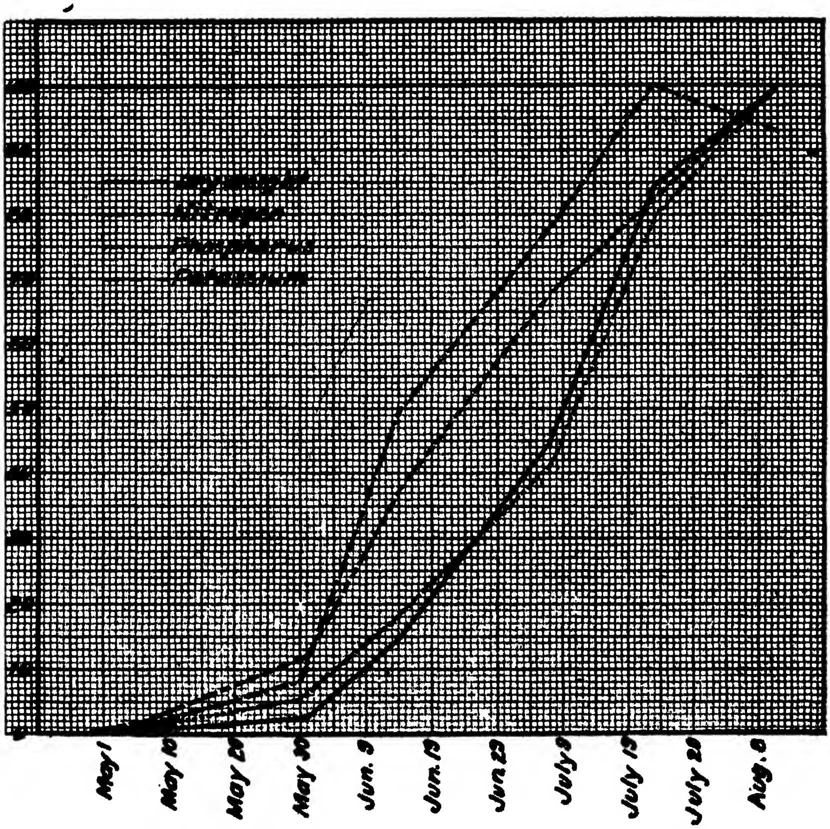

Fig. 2.—Relative dry weight and relative total content of nitrogen, phosphorus, and potassium in barley, data of Pfeiffer, et al, for 1919.

It is obvious that if plant composition is to be used as a criterion of soil conditions, the stage at which the crop is sampled for analysis may be highly important. The significance of this point is well illustrated by the data shown in Table 3, which reports the relative dry weights and the relative percentages and total contents of nitrogen, phosphorus, and potassium for corn grown at Wooster,

Ohio, upon two series of plats receiving widely different fertilizer treatments.

Although there are certain irregularities in the data presented due in part to errors of sampling, it is apparent that quite different

TABLE 2.—*Showing change in percentage composition of nutrient elements in dry substance at successive periods of growth.*

Date	Nitrogen	Phosphorus	Potassium
	%	%	%
	Barley, Data of Pfeiffer, et al, for 1919		
May 5	5.17	0.470	1.53
May 31	5.27	0.456	2.10
June 14	3.09	0.361	2.46
July 7	1.69	0.217	1.15
July 23	1.13	0.205	0.81
Aug. 11	1.23	0.230	0.68
	Corn Data of Ohio Station for 1926		
June 28	3.86	0.381	2.17
July 12	3.26	0.224	2.09
July 26	2.65	0.222	1.58
Aug. 9	2.46	0.245	1.84
Aug. 23	1.59	0.267	1.47
Sept. 6	1.51	0.222	1.00
Sept. 20	1.31	0.206	0.69
Sept. 27	1.19	0.214	0.78

TABLE 3.—*Relative dry weights and contents of nitrogen, phosphorus, and potassium in corn at successive periods of growth, Wooster, Ohio, 1926.*[a]

Date	Days after planting	Relative dry weight	Relative percentage of dry weight Nitrogen	Phosphorus	Potassium	Relative total content Nitrogen	Phosphorus	Potassium
June 28	44	508	195	134	139	535	724	644
July 12	58	532	89	100	112	470	515	580
July 26	72	271	93	91	121	252	277	302
Aug. 9	80	303	70	95	71	211	306	214
Aug. 23	100	147	84	64	69	124	95	101
Sept. 6	114	159	95	76	81	152	119	126
Sept. 20	128	125	97	77	108	120	97	134
Sept. 27	135	124	99	96	104	115	117	122

[a]Data represent average results from two plats receiving 3-12-4 fertilizer and 10 plats receiving 0-16-0 fertilizer. Data for plats receiving 400 pounds of 3-12-4 fertilizer in the hill are stated as percentage of corresponding data for plats receiving 225 pounds of 0-16-0 broadcast.

indication of the relative productive powers of the two series of plats is shown by the data for different sampling dates. As a whole, the total nutrient contents for the later periods agree best with the yields of dry matter produced by the end of the season. The total nutrient

contents at the earlier periods give an exaggerated idea of the relative productive capacities for the season, although agreeing fairly well with the dry weights for the early sampling dates. This tendency for data upon the total nutrient content of young plants to magnify differences in soil productivity might be advantageous in using plant composition as a guide to soil deficiencies, providing its existence were recognized and proper allowances made. The percentages of nutrients present fail in general to reflect the real differences in productive capacity, negative indications being secured for most sampling dates.

Associated with changes in the total composition, there occur, as the plant passes from vegetative into reproductive stages, certain movements of the individual elements within the plant itself, leading to their concentration in various parts of the plant. With the grain crops, for example, there is a movement of phosphorus and nitrogen into the seed parts and a movement of potassium into the stems and leaves as maturity is approached. At the same time the roots tend to show large losses of all three elements. Such changes must naturally be considered when attempting to use crop composition data for measuring soil differences.

The intake of nutrient elements by the plant is determined not only by its own physiological capacity at successive growth periods but is also dependent upon the whole category of environmental growth factors. Some of these, like the supply of any particular element, may operate directly upon the rate of intake, while others, like temperature, may operate through either their effect upon the plant itself or their effect upon biological and chemical processes in the growth medium.

It has already been observed that there exists a general relation between the intake of a given element and its supply under field conditions. A more exact relation might be expected to hold where plants were grown under controlled conditions, especially should the attempt be made to hold all other growth factors at the optimum point. For such conditions the well-known growth equation of Mitscherlich (12) has been found to describe fairly well the relation of yield to successive increments of the limiting nutrient. The nutrient intake does not appear, however, to be a similar function of the supply. This is illustrated by the graphs shown in Fig. 3 which represent data of Pfeiffer, Simmermacher, and Rippel (13) for the total dry weight and percentage and total nitrogen contents of oats grown in sand culture with abundance of other nutrients than nitrogen supplied. For purposes of comparison the data have been re-

calculated to a relative basis where the highest total weight, nitrogen content, and percentage have been taken as 100. The dry weight curve is of the usual logarithmic type and can be nicely fitted by the Mitscherlich equation.

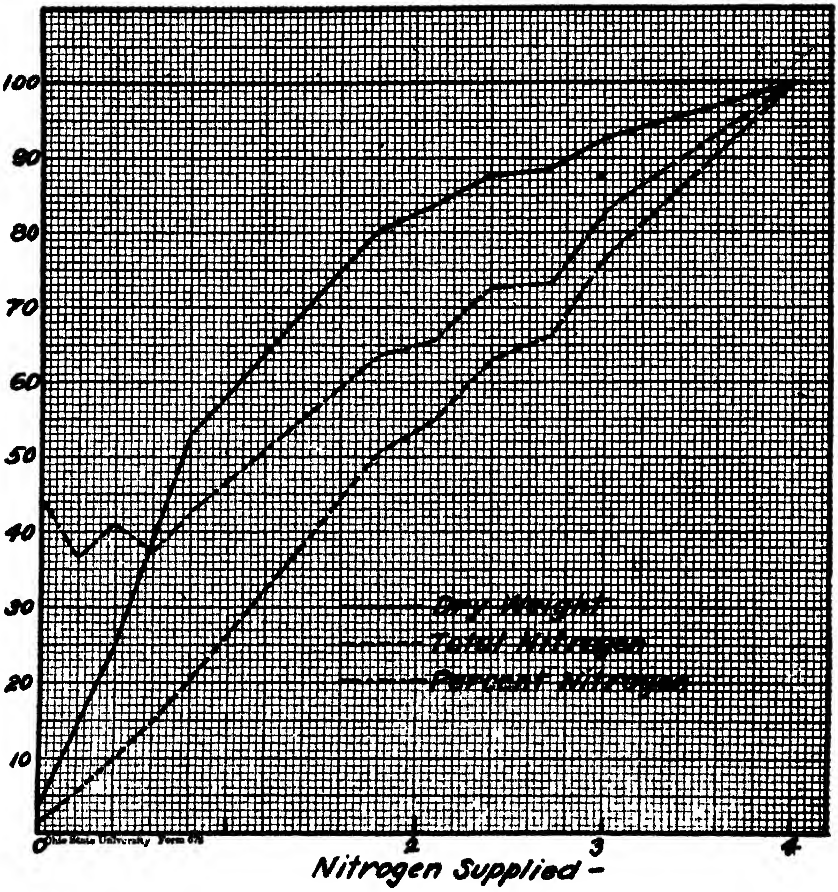

Fig. 3.—Relative dry weight, total nitrogen, and percentage of nitrogen in oats with increasing additions of nitrogen. Data of Pfeiffer, Simmermacher, and Rippel.

It is observed that the curve representing the intake of total nitrogen is not logarithmic in type, there existing instead an almost linear relation between the nitrogen supplied and the nitrogen taken in by the plant. It appears that the old idea of Liebig, according to which the growth of the crop bears a constant proportion to the supply of the limiting factor, more nearly fits the intake of nutrient elements than it does the growth of the plant. This general tendency

for the intake of a nutrient element to vary directly with the supply rather than with the actual needs of the crop has been found to hold more closely in the case of nitrogen and potassium than it does with phosphorus. Its effect is to produce what has been termed a "luxury consumption" of nitrogen or potassium when these are supplied in excess of the needs of the crop. It also leads to the result that a small crop produced as a result of an insufficiency of one nutrient may contain a higher percentage or even a greater total quantity of a second nutrient than a much larger crop produced where both nutrients are present in greater abundance. This makes it impossible to estimate the supply of a given nutrient in the soil from its content in the plant, unless it is assured that other growth factors are supplied in abundance, a condition which is by no means easy of attainment, especially under field conditions.

Much recent work has shown that the relative or actual needs of a plant for the nutrient elements are not constant throughout the growth of the plant. Conversely, the supplying or withholding of a nutrient from the plant at different periods of growth may produce quite different effects upon the growth of the plant and upon its intake of the particular nutrient. Duley and Miller (4) studied the effect of varying supplies of nutrients upon the yield and composition of the corn plant at different periods of growth. They divided the entire growth period into three equal periods and compared the effects of all possible combinations of two widely different nutrient levels for the three periods. It was found that the nutrient supply during the second period was far more important in the production of both vegetative parts and ears than was the supply during either the first or third period. On the other hand, the percentage of nitrogen and potassium in the plants was approximately proportional to the supply of nutrients during the period just previous to harvest. With phosphorus the percentage was much less influenced by variation in the nutrient supply. From these facts it follows that the content of a nutrient, potassium for example, found in a mature plant at harvest time might give an entirely misleading indication of the supply available during that period of the plant's growth when potash was most needed.

Aside from the question of nutrient supply there are a host of environmental factors that are known to affect the intake of nutrients by the plant. As examples may be mentioned temperature, reaction of growth medium, supply of oxygen and moisture, and the degree of competition. The influence of many of these factors has been incompletely studied.

Miller and Duley (14) have studied the effect of varying moisture supply upon the development and nutrient intake of corn at different periods of growth. They report that,

"As an average of all cases minimum moisture content gave a higher nitrogen content and a higher mineral content than where optimum moisture was applied, during any period of growth...... The percentages of both nitrogen and mineral elements usually decreased with the age of the plants. In most cases the decrease was more marked with optimum than with minimum moisture treatments."

Pfeiffer, Simmermacher, and Rippel (13) grew oats in sand culture at two levels of moisture and light supply and with increasing additions of nitrogen, phosphorus, and potassium. Reductions in either light or moisture resulted in a higher percentage composition for each of the three nutrient elements. Such reduction did not significantly alter the total intake of nitrogen by the plant but lowered the total intake of both phosphorus and potassium.

Wieszmann (15) studied the effect of diminished light supply upon the phosphorus and potash intake of young rye plants growing in undiluted soil in pots. His results show a reduction in total intake of both elements and at the same time an increased percentage composition with decreasing illumination. His results are not in agreement with those of Gunther (16) who studied the influence of variations in light intensity upon the absorption of phosphorus and potassium by rye seedlings grown under conditions of the Neubauer test and reported only slight influence of light upon the amount of nutrients absorbed. The apparent discrepancy may probably be attributed to the great difference in the degree of competition existing in the two cases. Under conditions of extreme competition, such as exist in the Neubauer procedure, the effect of variations in other factors than nutrient supply are apt to be largely masked.

The direct influence of competition upon the intake of nutrient elements is illustrated by work of Ames and Gerdel (17) who grew buckwheat plants in increasing dilutions of soil in quartz sand,

TABLE 4.—*Potassium removal by buckwheat seedlings under different degrees of competition.*

Weight of soil, grams	Total potassium, mgm	Potassium concentration %
1,600	49.5	1.384
200	14.2	1.131
100	7.3	0.961
50	5.1	0.918
0	3.7	1.200

other factors being kept constant. Ten plants to a pot were grown for 20 days using 0, 50, 100, 200, and 1,600 grams of soil in a total weight of soil and sand of 1,600 grams. In Table 4 are shown the total potassium and the percentage of potassium in the dry tops of the young plants.

The effect of variations in soil reaction upon the nutrient intake of plants has received much attention through studies of the effect of liming upon crop composition. It is impossible, however, in such work to determine whether differences in composition are due to changes in the supply of nutrients induced by chemical or biological effects of the treatment or whether they result from the influence of varying reaction upon the physiological availability of the nutrients themselves. Davidson (18) has recently studied the effect of hydrogen-ion concentration on the absorption of phosphorus and potassium by wheat seedlings in solution culture where complete solubility of nutrients was maintained. He reports that more phosphorus was absorbed by the seedlings from solutions with initial pH values of 5.0 and less from those with pH values of 6.0 and 7.0, showing that the physiological availability of phosphorus depends upon the reaction of the medium. Here again, conditions of extreme competition may mask the influence of the factor in question, for as Gunther (16) has shown, the absorption of potassium and phosphorus by rye seedlings in the Neubauer test is almost unaffected by changing the pH of the soil from an initial value of 5.0 to 6.5 and 8.0 by the addition of $CaCO_3$.

Further comment upon the importance of environment upon nutrient intake is probably unnecessary. Mention should be made, however, of still another factor which may influence nutrient absorption greatly, namely, the specific inherent feeding capacity of the plant itself. That different species of plants may differ widely in their capacity to absorb nutrients when supplied in different chemical or physical forms is now generally recognized. Herein lies one of the fundamental weaknesses of the Neubauer seedling method as now employed, since the nutrient absorption of a single plant, rye, is used to determine the nutrient needs of all other crop plants. Not only do plant species differ in feeding power, but it is reasonable to suppose that individuals of the same species also vary. For example, commercial corn varieties are so heterozygous in character as to lead one to expect considerable variation in the power of individual plants to absorb nutrients from the same growth medium. In such cases chemical tests upon limited numbers of plants are apt to give inaccurate indications of nutrient absorption by the crop as a whole.

We are now ready to consider some of the methods being employed at the present time to gain information regarding soil deficiencies from chemical examination of plants grown upon the soil.

The most widely used procedure is probably the seedling method of Neubauer. Originally proposed by Neubauer and Schneider (19) in 1923, the method has been extensively studied in Europe and has received some attention in this country. That it is held in high regard by certain German workers is evidenced by the fact that at least one experiment station in that country is now employing it in a wholesale manner for estimating the nutrient requirements of field soils.

The details of the Neubauer method are essentially as follows:

In the bottom of a small glass dish, having a diameter of approximately 11 cm and a depth of 7 cm, is placed 100 grams of carefully prepared soil, mixed with 50 grams of pure sand. Over this soil and sand mixture the greater portion of 250 grams of sand is spread, a sufficient amount for a ½-cm covering over the seeds being reserved. A small glass tube for aeration and watering is placed in the center of the dish. After the dishes are prepared 100 carefully selected rye seeds are planted, water is added, and the weight of the dishes obtained.

Neubauer states that the seed should weigh about 40 grams to the thousand, and should be treated with a chlorphenolmercury compound, "Uspulun." A kilogram of seed is treated for about 1½ hours with a liter of a 0.1% "Uspulun" solution containing 0.3 gram sodium hydroxide, then dried on blotting paper and allowed to remain exposed to the air for a week. The seeds are germinated by keeping the dish in a moist warm place After 17 days the seedlings with their rootlets are removed from the soil and sand, and the phosphorus and potassium contents determined.

The factors of technic which might be expected to influence the results secured by the Neubauer test have been given some study.

Reference has already been made to the work of Gunther (16) in which no appreciable effect of light intensity upon the absorption of potassium or phosphorus was found. Kruppa (20), on the other hand, found significant differences in the absorption of both phosphorus and potassium depending upon the light intensity, highest absorption taking place in full illumination, slightly less in darkness, and considerably less in the case of "half light" than with either full illumination or complete darkness.

Hahne (21) found only small differences in absorption, depending upon whether the seedlings were grown in direct light, diffused light, or darkness. He found differences of 30 to 40% in the absorption of potassium and over 50% in the absorption of phosphorus for

plants grown at a temperature of 22° to 23° C as compared to 9° to 12°C, the highest absorption taking place at the higher temperature.

Kruppa (20) reported that increasing water additions up to a certain point gave increasing absorption of both phosphorus and potassium.

Neubauer (19) found variations in the absorption depending upon the variety and kernel weight of the rye seed used, differences of as much as 10 mgm in potassium and 2.4 mgm in phosphorus resulting from the use of light as compared to heavy seed.

It has already been noted that Gunther (16) found no change in the absorption of phosphorus and potassium from an acid soil with increasing additions of $CaCO_3$. Further study of the effect of reaction on the results secured by the method is probably needed.

Rye has been the test plant quite generally used by German workers. Some study has been made, however, of the comparative absorptive capacities of seedlings of different species of plants. Kruppa (20) compared barley, wheat, and oats with two varieties of rye. Significant differences in the absorption by the different species was observed. Barley showed highest absorption of phosphorus and lowest absorption of potassium. Rye showed the highest absorption of potassium and the lowest absorption of phosphorus.

Ames and Gerdel (17) compared the potassium absorption of wheat and rye seedlings. Slightly more potassium was taken up by the former. They found it easier to secure seed of high germination and uniform weight with wheat than with rye and, therefore, selected the former plant for most of their later studies on the method. These same workers (22) compared the potassium absorption of wheat, corn, and soybean seedlings. Large differences in absorption were observed for the three plants, but no consistent relation in absorptive capacity for the different species was found when results from different soils were compared. In a recent comparison of potash absorption by rye and buckwheat seedlings the authors found the greater absorption in the case of rye on unlimed soils and the opposite on limed soils.

It should be remembered that as the test is now being used rye is employed as the test plant and from its absorption is estimated the needs of other crops. It is obvious that differences in the absorptive capacities of different species, unless consistent for different soils, would lead to failure of the method.

In the Neubauer procedure no nutrients are supplied other than those contained in the soil used. It is conceivable that more complete removal of a particular element, potassium for example, would

result if additions of nitrogen and phosphorus were made, thus preventing any possible limitation in the development of the seedlings due to an insufficiency of these elements. Ames and Gerdel (22) investigated this question and found that additions of nitrogen and phosphorus, singly or in combination, produced significant increases in the removal of potassium by wheat seedlings. These increases, however, were not large in comparison to the total removal.

The method appears to be subject to considerable experimental error which is frequently difficult to explain. Even with the most careful work, it is not uncommon to get differences of as much as 3 or 4 mgm of potassium removed by duplicate cultures. Since the removal in the blank must be deducted to determine the removal from the soil itself, this throws all the error upon the latter quantity. Hahne (21) places the limits of accuracy for the analyses of the plants at 1.0 mgm of P_2O_5 and 3 mgm of K_2O. Moreover, the blank, determined by the removal from pure sand, is, in most cases studied by the authors, large in proportion to the total removal. There is also some question as to method of calculating the blank. This arises from the fact that 100% germination is seldom secured. In the process it has been shown that considerable potassium moves out of the seed into the sand and is then reabsorbed by the growing seedling. There is considerable uncertainty as to how much potassium may move out of the seeds that do not germinate and be absorbed by the seedlings produced by the remainder. This leads to the question as to whether the blank should be taken as the total removal or should be figured on the basis of the removal per plant.

Kruppa (20) applied the Neubauer test for phosphorus and potassium to 33 soil samples (each a composite of 8 to 10 portions) taken in a regular manner over an area of 1¼ hectares (3.1 acres) of land which seemed to be very uniform as judged from the appearance of the crop growing upon it. His results showed variations in potash removal from 10.8 to 20.3 mgm and in phosphoric acid from 0 to 7.3 mgm. He considered that these variations were much larger than the probable variations in nutrient needs of the area.

In using the method to estimate the nutrient needs of various crops it is customary to set a "limiting number" for each crop. This "limiting number" is the nutrient removal by the rye seedlings from a soil which contains just enough of the nutrient in question that further additions are apt to be unprofitable for the particular crop. Soils showing smaller removals are supposed to respond to additions of the nutrient in proportion as they fall below this value. Different workers do not agree as to the size of these limiting numbers.

Table 5 shows the limiting numbers used by Neubauer as compared to those of Roemer (cited by Gunther, 16).

TABLE 5.—*"Limiting Numbers" for Neubauer test proposed by Neubauer and Roemer for different crops.*

Crop	P_2O_5 Neubauer mgm	P_2O_5 Roemer mgm	K_2O Neubauer mgm	K_2O Roemer mgm
Rye	8	4	14	20
Oats	7	4	18	20
Barley	7	6	18	30
Wheat	8	6	14	30
Potatoes	10	6	37	40
Sugarbeets	12	8	39	30

Much difference of opinion exists among foreign workers as to the utility of the method, despite numerous comparisons of the results secured by its use with those of field or pot tests or with chemical laboratory methods. Blanck and Scheffer (23) report that comparisons with vegetative tests show that the method has no value as an indicator of nitrogen needs. Densch and Pfaff (24) found no general agreement between potassium and phosphorus requirements indicated by the Neubauer test and the response shown to additions of these elements in pot and field experiments. Favorable results for the Neubauer test in comparison with field tests are reported by Egner (25) and Gericke (26). Meyer and Wodarz (27) worked with soils of known field response and concluded that the Neubauer test was of no value for determining phosphorus needs.

Several comparisons are reported between the phosphorus removed by the Neubauer method and its supply as indicated by the method of Lemmermann (28). According to the latter, the relative supplies of this element in available form are shown by the percentage of the total phosphorus (soluble in 10% hydrochloric acid) that is extractible with 0.5% citric acid. Engels (29, 30) found a general agreement between the two methods but a disturbing number of exceptions. He reports the results of the Lemmermann method to be in better conformity with the response shown in field tests. Van der Spuij (31) found little agreement between the two methods and considers the P_2O_5 soluble in 1% citric acid a better indicator than either of these tests. Blanck (32) found Lemmermann's method in better agreement with field response than Neubauer's method. Lemmermann (33, 34, 35) reports general agreement between his method and that of Neubauer, but thinks that the Neubauer method needs considerable refinement before it can give results of certain value. Niklas (36) compared the methods of Lemmermann and

Neubauer with his own azotobacter method and obtained fair agreement for the three methods.

Honcamp and Steinfatt (37) used the Neubauer method for determining the root-soluble P and K in several subsoils. Large differences noted between different subsoils indicated that examination should not be confined to the surface layer when determining the probable needs of these elements.

Gericke (26) determined what percentage of the P and K supplied in the form of water-soluble salts was recoverable in the Neubauer method. Only 15.2% of the P added was recovered, although this was increased to 39.3% where additions of $CaCO_3$ were made. With potassium, 37.6% was recovered without additions of $CaCO_3$ and 73.1% with such additions.

Niklas, Purckhauer, and Poscheurieder (38) determined the root-soluble P in a number of soils of different geological origin and suggest making survey maps giving the divisions of phosphorus need similar to maps made by them to show the lime needs of soils.

Bätz (39) used the Neubauer method for studying the effect of freezing upon the availability of the phosphorus and potassium of soils.

Ames and Gerdel (22) at the Ohio Station have studied the factors of technic affecting the Neubauer test. Attention has already been called to certain of their results. They also applied the Neubauer test to soils taken from certain plats in the old fertility experiments at Wooster. Working with wheat seedlings they found the test of no value for measuring available phosphorus, there being no significant difference between the phosphorus removal from any of the plat soils and that contained in the check seedlings grown upon pure quartz sand. In the case of potassium the method differentiated satisfactorily between plats that had been regularly fertilized with potash fertilizers and those that had received no potash.

The authors have recently done further work along the same general lines. The soils studied were taken from both the limed and unlimed ends of selected plats in Section D of the five-year rotation fertility experiment. These soils have been under regular treatment since 1894. Root-soluble K has been determined by the Neubauer method, using both buckwheat and rye seedlings. For comparison, determinations have been made of the exchange potassium in these soils by the method of Schollenberger (40) and of the potassium soluble in N/100 HNO_3. Root-soluble P has been determined by the Neubauer method, using rye seedlings. Phosphorus soluble in N/10 H_2SO_4, using a soil-solution ratio of 1:50, has also been determined

Table 6.—*Data on treatment, yields, and potash removal for field plat soils in five-year rotation fertility experiment, Wooster, Ohio.*[a]

Plat No.	Treatment in pounds per rotation: Muriate of potash	Treatment in pounds per rotation: 16% superphosphate (acid phosphate)	Treatment in pounds per rotation: Nitrate of soda	Total produce, 1923–27, pounds	Corn yield, 1924: Grain bushels	Corn yield, 1924: Stover, pounds	Pounds of potassium per 2,000,000 pounds of soil: Neubauer Buckwheat	Neubauer Rye	Exchange	Soluble in N/100 HNO_3	Percentage of potassium contained in: Corn plants, 1927[b]	Alsike clover plants, 1927
						Unlimed						
3	260	——	——	2,684	1.86	520	162	173	214	154	3.28	2.19
7.10 (average)	——	——	——	2,540	1.00	420	50	88	78	70	1.57	1.11
8	260	320	——	6,764	9.64	1,300	89	112	188	120	2.35	1.52
2	——	320	——	4,505	1.14	500	66	89	90	74	1.18	1.08
11	260	320	440	9,928	13.43	1,460	106	135	194	122	3.55	2.01
6	——	320	440	7,208	6.29	920	38	57	74	64	1.25	.98
						Limed						
3	260	——	——	12,216	27.86	2,100	143	70	158	72	2.52	1.14
7.10 (average)	——	——	——	8,630	5.90	890	113	22	68	51	.79	1.06
8	260	320	——	19,930	26.36	2,080	141	66	124	60	1.15	1.11
2	——	320	——	15,497	19.57	1,800	129	22	76	34	1.08	.72
11	260	320	440	24,676	51.07	3,080	142	73	112	62	2.55	1.14
6	——	320	440	16,223	12.71	1,440	92	26	66	34	.77	.84

[a]Data are for Section D except where otherwise noted.
[b]Corn from Section A of five-year rotation experiment.

TABLE 7.—*Data on treatment, yields, and phosphorus removal for field plats in five-year rotation fertility experiment, Wooster, Ohio.*[a]

Plat No.	Treatment in pounds per rotation: 16% superphosphate (acid phosphate)	Muriate of potash	Nitrate of soda	Total produce, 1923–27, pounds	Wheat yield, 1926, bushels	Pounds of phosphorus removed per 2,000,000 pounds of soil: Neubauer	Soluble in N/10 H_2SO_4 Soil: Solution = 1:50	Corn plants, 1927[b] %	Alsike clover plants, 1927 %
				Unlimed					
2	320	—	—	4,505	10.33	0	124	0.224	0.183
7.10 (average)	—	—	—	2,540	3.79	0	90	0.228	0.145
8	320	240	—	6,764	15.83	0	120	0.241	0.139
3	—	240	—	2,684	1.92	0	74	0.242	0.131
11	320	240	440	9,928	24.66	0	112	0.262	0.174
9	—	240	440	4,410	5.55	0	88	0.242	0.154
				Limed					
2	320	—	—	15,497	28.42	0	—	0.395	0.173
7.10 (average)	—	—	—	8,630	11.54	0	—	0.402	0.137
8	320	240	—	19,930	37.08	0	—	0.344	0.129
3	—	240	—	12,216	17.25	0	—	0.284	0.157
11	320	240	440	24,676	43.75	0	—	0.312	0.128
9	—	240	440	14,138	16.92	0	—	0.256	0.147

[a]Data are for Section D except where otherwise noted.
[b]Corn plants from Section A of five-year rotation experiment.

upon the samples from the unlimed ends of all plats. Potassium and phosphorus concentrations have also been determined in young corn plants sampled June 30, 1927, on Section A of the same experiment and in alsike clover plants taken in 1927 from Section D.

The data for potassium are shown in Table 6 and that for phosphorus in Table 7. Data showing the total pounds produce for the five-year period, 1923 to 1927, and the yield of the last corn and wheat crops grown on Section D are also included as a basis for judging the response to potash and phosphorus additions.

The results of the Neubauer method with both buckwheat and rye seedlings are seen to reflect soil differences due to additions of potash fertilizers. The same may be said for the data on exchange potassium and potassium soluble in N/100 HNO_3. The percentage concentration of potassium in the young corn and alsike clover plants shows similar differences due to potash treatment. For the unlimed soils it is impossible to state which of the various methods more nearly indicates the true potash needs of the soil as indicated by crop response. All of the data, excepting the absorption by buckwheat seedlings, indicate less reserve of available potassium in the limed than in the unlimed soils. This agrees with conclusions reached from studies of the yield trends for the limed and unlimed ends of the individual plats and is probably attributable to the greater potash removal by the larger crops grown upon the limed ends. It will be observed, however, that with all soils, excepting that from plat 3, the buckwheat seedlings were able to absorb greater amounts of potassium from the limed than from the unlimed soils. This is clearly out of accord with the known facts as regards the relative supplies of available potash present and points to a high degree of specificity in the ability of different plants to use different forms of soil potash and to quite unlike effects of liming upon their absorptive powers for this element. On the whole, one is unable to conclude that the Neubauer seedling method offers any advantages over the strictly chemical methods for exchange potassium or that soluble in dilute acids. The latter are certainly simpler and subject to less experimental error.

The results for the phosphorus absorption by rye seedlings shown in Table 7 are disappointing in that there is no positive absorption of phosphorus in excess of the pure sand checks for any of the soils. In fact, the phosphorus removal from these soil cultures was in all cases a fraction of a milligram less in the blank. The percentage concentration of phosphorus in the young corn and alsike clover plants also fails to show any consistent agreement with the plat

treatment. Only in the case of the results for dilute acid-soluble phosphorus do we find a consistent indication that treatment with superphosphate (acid phosphate) has increased the reserve of available phosphorus in the soil. The authors are forced to conclude that the Neubauer test has little, if any, value as an indicator of phosphorus needs of the soil. They are also unable to discover in their own work or in the work of others any justification for giving preference to the Neubauer method over the strictly chemcial methods of investigating the supplies of available potassium. All methods which are based upon a determination of the amount of a given nutrient present in the soil at a single sampling date and in such form as to be extractible under controlled laboratory conditions, whether they be physiological or chemical in nature, are subject to the same limitations in that they disregard the differential feeding power of plants and the dynamic nature of the plant-soil relationship.

Gilbert and co-workers (41, 42) at the Rhode Island Station have recently attempted to gain information regarding the current nutrient needs of crop plants by determining the amount of phosphate phosphorus, potassium, and nitrate nitrogen present in the juice from different plant tissues sampled at some particular period in the growing season. (For methods see Gilbert, 43.) They report results with various field and garden crops grown upon soils variously fertilized with N, P, and K. They find a general correlation between the concentrations of mineral nutrients in the plant solutions and the applications of chemical fertilizers. Largest fluctuations during the season were noted with nitrate nitrogen, the smallest with potassium, while phosphorus was intermediate in this respect. They suggest using the current mineral nutrient content of the plant as an index of fertilizer needs and further suggest tentative critical concentrations for each nutrient as follows: Potassium, roots or tops, 3,000 p.p.m.; phosphate phosphorus, roots, 20 p.p.m.; nitrate nitrogen, blades of leaves, 300 p.p.m.

The utility of the method may be questioned on the ground that the nutrients present in the plant solution at any one time do not reflect the supply during the entire growing period, but rather the supply for the period immediately preceding the sampling date. Gilbert and Hardin (41) show that side dressings with nitrogen fertilizers are quickly reflected in the nitrate content of the plant solution. Moreover, direct correlation of the nutrient content in the plant solution with that available in the soil is only observed where the nutrient in question is operating as a limiting factor.

Gilbert, McLean, and Adams (42) found that with low applications of phosphoric acid the nitrate nitrogen in the plant was high and vice versa. The lack of available manganese, leading to a chlorotic condition, also greatly increased the nitrate nitrogen content of the plant solution. Fluctuations in weather conditions materially influenced the concentration of all three elements in the plant solution. The authors feel that much further study is needed upon the plant solution method before an accurate opinion can be formed as to its probable utility.

A method for using plant composition as an index of soil nutrient supplies for the corn crop was recently proposed by Hoffer of the Indiana Experiment Station (44). After extensive study of the accumulation of iron and aluminum in the corn plant, especially in the nodal tissues, first as related to susceptibility to and injury by the corn root-rot organisms (45) and later as related to nutrient deficiencies in the soil (46), Hoffer concluded that the accumulation of iron in the nodal tissues of the mature corn plant is correlated in a negative manner with the supply of available potassium. The iron test is made by first splitting the stalks lengthwise and then adding to the freshly cut nodal tissue a few drops of a 10% solution of potassium thiocyanate followed by the addition of a drop or so of a dilute solution of hydrochloric acid. The development of a red color indicates the presence of iron, and simultaneously, if in abundance, a lack of potash.

Hoffer has also proposed a method for estimating the supply of available nitrogen which the corn plant has had at its disposal based upon the assumption that the nitrate content of the soil is reflected in the nitrate content of the stalk. The test is performed by applying a few drops of a 1% solution of diphenylamine in 75% sulfuric acid to the internodal tissue of the split corn stalks. If nitrates are present, a blue color develops, and the greater the quantity of nitrates present the more intense the blue color. In the absence of any color, nitrogen starvation is indicated.

After applying these two methods to corn grown upon a wide variety of soils in the Central West, and upon numerous experimental plats whose response to potash and nitrogen fertilizers had been established, Hoffer was sufficiently convinced of their utility that he recommended their use in a practical way for diagnosing the fertilizer needs of field soils. They are now being used extensively by extension specialists and county agents in Indiana for this purpose.

Following considerable discussion of these methods in the agricultural press, numerous inquiries regarding their utility under

Ohio conditions were received by the Ohio Experiment Station. To answer this question, the stalk tests were applied to corn grown in 1926 upon fertility plats situated on six different experimental farms representing most of the leading soil types upon which corn is grown in the state. The results of this study, reported by Welton, Morris, and Gerdel, were not such as to warrant placing much reliance upon the practical utility of the tests. Frequently, large variations were found in the results obtained on any given group of representative stalks selected under conditions as uniform as the eye could detect. The average results for the stalks selected from differently fertilized plats failed in general to reflect the soil treatment or to correlate with the known response to either potassium or nitrogen fertilizers. The general conclusion was reached that the tests, in their present form, are not adapted to practical use under Ohio conditions. Some further study of the tests has been made upon corn grown upon variously treated plats at Wooster during the past season.

In order to secure data as to the relative variability to be expected in the iron test when applied to open-pollinated corn as compared to selfed strains, the test was applied to approximately 50 stalks selected from each of two adjacent areas having uniform soil and identical treatment. The one area was planted to commercial Clarage corn, the other to a selfed line developed from this variety. Table 8 shows the distribution of the results secured, the intensity of coloration noted being indicated by means of a letter scale according to which an absence of color is designated as C—and a heavy coloration by the letter E.

TABLE 8.—*Results of iron test upon open-pollinated and in-bred corn grown under identical soil conditions.*

	Number of stalks showing various degrees of coloration								Average of all tests
	C—	C	C+	D—	D	D+	E—	E	
Open-pollinated	5	30	11	4	6	2	0	0	C+
In-bred	0	3	7	13	24	2	0	1	D—

No large difference in the degree of variability is to be found between the results for the open-pollinated as compared with the inbred corn. With both, the variability is so great as to lead one to question the results which might be secured from testing only four to six stalks, the numbers commonly used in the practical application of the test.

A study was also made of the iron test as applied to approximately 50 random stalks of the same variety of corn grown upon two areas of the same type of soil which were selected to represent extreme

differences in fertility. The one area is the same as that used for the foregoing comparison of open-pollinated and in-bred corn. This area has regularly received heavy applications of stable manure and chemical fertilizers and is in a very high state of fertility having yielded approximately 20 tons of silage per acre the past season. The other area is a roadway in Section A of the five-year rotation fertility experiment which has received no manure or fertilizer since 1894 and is now in a highly exhausted condition. Table 9 shows the results of the iron tests upon the two sets of stalks. For comparison, the amount of exchange potassium in the soils of the two areas is shown.

TABLE 9.—*Results of iron test upon the same variety of corn grown upon two areas of uniform soil type but representing extremes in fertility level.*

	Pounds of exchange potassium per 2,000,000 pounds of soil	Number of stalks showing various degrees of coloration C—	C	C+	D—	D	D+	E—	E	Average of all tests
Fertile soil	279	5	30	11	4	6	2	0	0	C+
Infertile soil	83	6	23	5	7	7	1	0	3	C+

It would appear that the value of a method which fails to reflect differences in potash supply for soils of such widely different fertility might reasonably be questioned. Further evidence of this fact is to be found in Table 10 which contains the results of the iron tests made in the fall of 1927 upon corn grown upon the limed ends of selected plats in the five-year rotation fertility experiment.

TABLE 10.—*Results of iron test upon corn grown upon variously treated plats in five-year rotation fertility experiment at Wooster, 1927.*

Plat No.	Treatment in pounds per rotation: Muriate of potash	16% super-phosphate (acid phosphate)	Nitrate of soda	Degree of coloration in stalks: 1	2	3	4	5	6
2	—	320	—	D—	D—	D—	C+	C+	C+
3	260	—	—	C+	C+	C+	C+	D—	D—
4	—	—	—	D—	D	D	C	C+	C+
6	—	320	440	D+	C	C	C—	D	D
8	260	320	—	C—	C+	D	D	D—	D
11	260	320	440	C	C+	C	C	C+	C

It is obvious that the test fails to reflect the fertilizer treatment. This is especially significant when it is considered that comparisons of yield data for plats 2 and 8 and plats 6 and 11 prove conclusively

that a condition of extreme potash starvation now exists on plats 2 and 6.

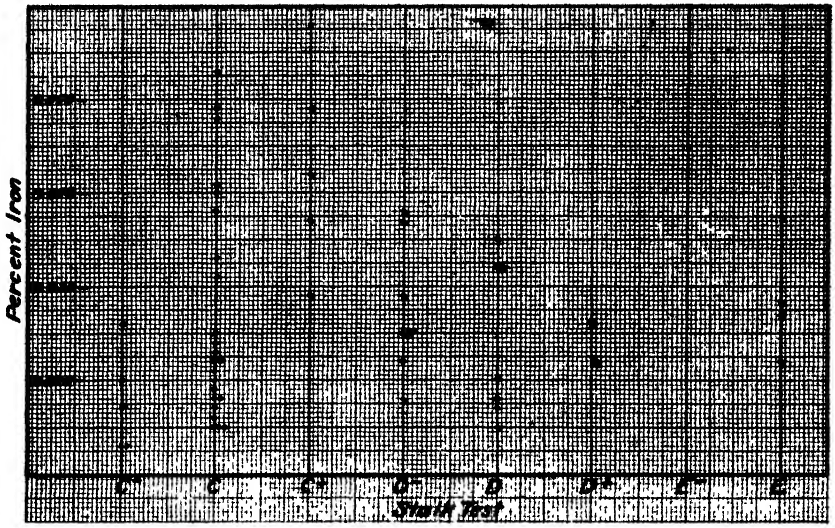

Fig. 4.

A similar study was made by applying the iron tests to Burr-Leaming corn grown upon an infertile Canfield silt loam soil with different manure and fertilizer treatment. The results are given in Table 11.

TABLE 11.—*Results of iron test upon corn grown upon field plats receiving different manure and fertilizer treatment, Wooster, 1927.*

Plat No.	Treatment per acre: Manure, tons	Fertilizer analysis	Amount (in hill) pounds	Degree of coloration in stalks: 1	2	3	4	5	6
13	—	—	—	C	C+	C+	C	C+	C
22	—	—	—	C+	C+	C	C	C+	C+
25	—	—	—	D—	C	C	C	C	C+
17	—	0-16-0	150	C	C	C+	C+	C+	C
18	—	0-12-4	200	C	C+	C+	C	C	C—
20	—	3-12-4	100	C	C	C	D—	D—	C
21	—	3-12-4	200	C—	C	C	C	C	C
23	—	3-12-4	400	D	C	C	C	C	D—
14	8	—	—	D—	C	C	C—	C	C
15	8	3-12-4	100	C	C	C+	C	C	C+
26	8	3-12-4	200	C+	C	C	C	C	C
27	8	3-12-4	400	C+	C+	C	C	C	C+

Here again the test failed to reflect the treatment given.

The fact that the authors frequently observed rather heavy iron tests upon stalks showing an abundance of potash by the microchemical chloroplatinate test led to an investigation of the iron-potash relationship in the nodal tissue of the 50 stalks selected from

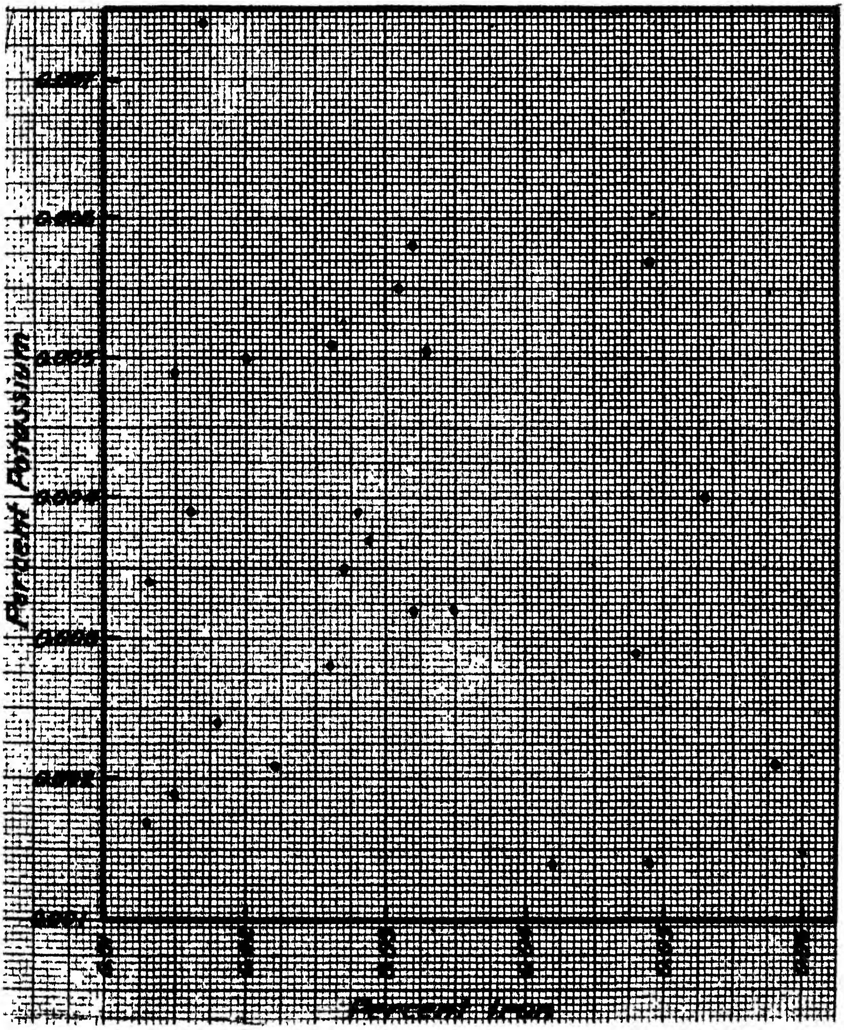

Fig. 5.

the roadway of the five-year rotation fertility experiment. The plan was to split each stalk using one-half for the iron test by the usual method. One-half-inch sections of the nodal tissue were cut from the other half of the stalk and these used for a quantitative determi-

nation of iron and potash. Iron was determined for all stalks and potash upon a selected group of 25 stalks showing the extreme range of iron content. Fig. 4 shows the relation of the coloration produced in the colorimetric stalk test to the percentage of iron found in the ash of the nodal tissue. No evidence of correlation is apparent. Fig. 5 shows the relation of total iron content to the potash content. Again no correlation is indicated. Fig. 6 shows the relation between

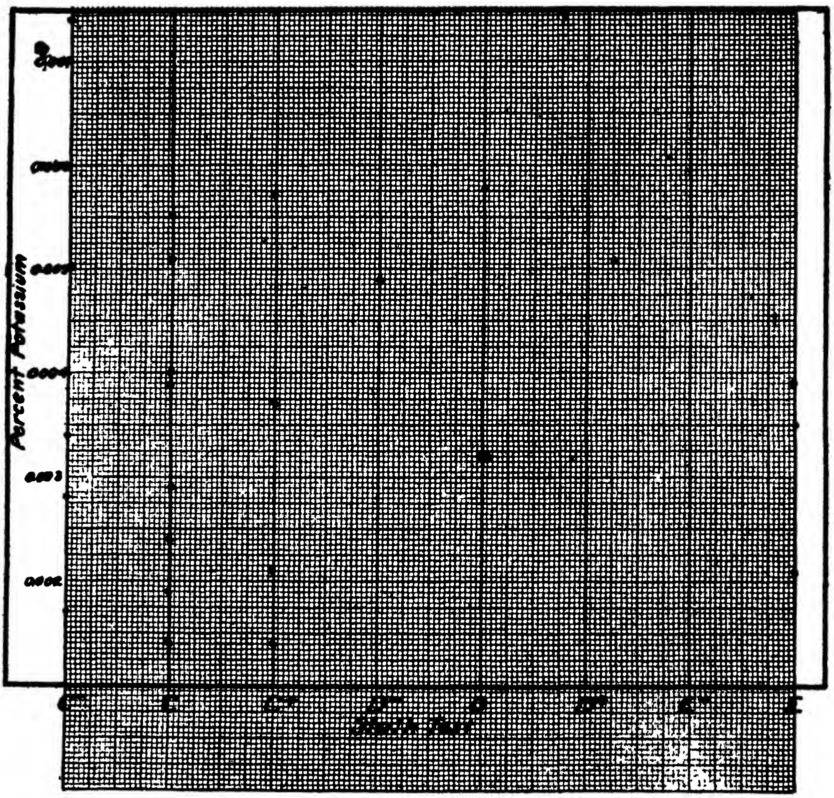

Fig. 6.

the colorimetric stalk test and the potash content. No apparent correlation exists. The conclusion seems warranted that the indications given by the stalk test do not vary either with the total iron content or the potash content. It remains to be proved whether the stalk test is any better indicator of potash needs than the actual potash content of the plant, the value of the latter having yet to be established.

TABLE 12.—*Results of nitrate test on corn grown upon unlimed ends of selected plats in a five-year rotation fertility experiment, Wooster, 1927.*

Plat No.	Treatment in pounds per acre on corn: Nitrate of soda	16% super-phosphate (acid phosphate)	Muriate of potash	Degree of coloration in stalk: 1	2	3	4	5	6
4	—	—	—	T	O	T	O	O	O
5	160	—	—	O	O	T	O	O	T
8	—	80	80	T	+	+	++	O	+
11	160	80	80	O	++	O	++	+++	++
12	240	80	80	+++	O	+++	+++	++	++++
18	Manure, 8 tons			+++	T	O	T	+	O
20	Manure, 4 tons			+	+	+	+	+	+

A less extensive study was made in the past season of the nitrate test. Table 12 gives the results of its application to corn from the unlimed ends of selected plats from the five-year rotation fertility experiment.

A comparison of the results for plats 4 and 5 shows no indication of any effect due to the nitrate applied to the latter plat. A similar comparison for plats 8, 11, and 12 gives evidence that the nitrate additions are reflected in the stalk tests, although some extreme differences between individual stalks of the same plat are apparent. The results for the manured plats, 18 and 20, do not reflect the relatively large applications of nitrogen given these plats.

The results of the nitrate test applied to Burr-Leaming corn for which the iron test data are reported in Table 11 are shown in Table 13.

TABLE 13.—*Results of nitrate test upon corn grown upon field plats receiving different manure and fertilizer treatment, Wooster, 1927.*

Plat No.	Treatment per acre: Manure, tons	Fertilizer analysis	Amount (in hill) pounds	Degree of coloration in stalk: 1	2	3	4	5	6
13	—	———	——	O	O	T	O	O	O
22	—	———	——	O	T	T	O	T	O
25	—	———	——	T	O	T	T	+	O
17	—	0-16-0	150	+	O	T	O	O	O
18	—	0-12-4	200	+	+	T	+	+	++++
20	—	3-12-4	100	O	++++	T	O	O	O
21	—	3-12-4	200	O	T	O	—	——	T
23	—	3-12-4	400	+++	+	++	O	+++++	T
14	8	———	——	++	+++	+	++	+	T
15	8	3-12-4	100	+++	O	T	O	++	+++
26	8	3-12-4	200	+	+	T	T	++++	T
27	8	3-12-4	400	+	+++++	T	+	T	+++

Here again a disturbing irregularity exists between the results from individual stalks from a single plat. While there is a higher proportion of stalks showing abundance of nitrates upon the more liberally treated plats, it cannot be said that the test reflects the treatment given, except in a very general way.

From a study of all the available data the authors do not consider the stalk tests for either potash or nitrogen requirements as sufficiently reliable to warrant their practical use under Ohio conditions.

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THE VITALITY OF SOYBEAN SEED AS AFFECTED BY STORAGE CONDITIONS AND MECHANICAL INJURY[1]

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The seed of the soybean (*Soja max*) has been regarded by some as being unusually sensitive to adverse storage conditions. In view of the rapidly increasing economic importance of this crop, it is highly desirable that some definite knowledge of this matter be obtained based upon exact observations, and it was to this end that the investigation, of which the following experiments are a part, was undertaken.

The experiments presented in this paper fall under two headings, *viz.*, storage conditions affecting the longevity of soybean seed and the effect of threshing injury upon the longevity and vigor of soybean seed.

STORAGE CONDITIONS AFFECTING LONGEVITY OF SOYBEAN SEED

Various theories have been advanced to explain differences in longevity in seeds. Crocker (8)[3] states that there is no general rule for the curing and storage of seeds. Duvel (11) found that garden seeds lost their vitality very rapidly in warm, humid climates, but maintained it for long periods in cold climates. Welton (20), Sifton (19), Carruthers (7), Acton (1), Dorph-Peterson (9), Asprit and Gain (3), Harrington (13), Bacquerel (4), Blackman (5), Lespeschkin (16), and others have worked with seeds of different ages. As a general summary of the work of these investigators, it may be stated that loss of vitality has been attributed to desiccation, high temperature, loss of oxygen, weather conditions at harvest time, inheritance, loss of diastatic and proteolitic activities, permeability of seedcoats, denaturing of protein, etc. In most cases, however, the age of the seed was the only factor considered, different conditions of storage not being taken into account.

In the present investigation, the plan was to subject soybeans of a few common varieties to several different conditions of storage. The work was continued for three seasons during which weather conditions differed widely at harvest time. New lots of beans and new storage conditions were introduced each fall. For the present purpose, the data for the first two seasons only are included since they represent diverse conditions.

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[3]Reference by number is to "Literature Cited," p. 854.

TABLE 1.—*Water content and percentage of germination of untreated soybeans stored in different ways, Series A, crop of 1924.*

Lot No.	Variety and manner of storage	Dec. 13, 1924		Oct. 18, 1925		Dec. 20 1926		March 10 1927	
		Water	Germination	Water	Germination	Water	Germination	Water	Germination
		%	%	%	%	%	%	%	%
1	Manchu in burlap bag	10.2	96	11.2	92	11.0	95	11.5	85
2	Midwest in burlap bag	11.9	97	9.8	96	11.7	92	12.5	72
3	Manchu in cotton bag	11.2	97	9.9	82	11.5	98	11.6	78
4	Midwest in cotton bag	12.7	96	11.4	96	13.2	96	12.9	76
5	Manchu in open tank	8.7	89	10.1	96	12.3	98	11.1	81
6	Midwest in open tank	12.8	98	11.3	98	13.2	90	12.3	71
7	Manchu in closed tank	9.4	93	8.8	94	11.0	97	10.3	73
8	Midwest in closed tank	11.2	98	12.1	94	11.7	95	12.3	74
9	Manchu in screen bin	11.5	97	9.2	96	11.9	95	12.7	78
10	Midwest in screen bin	12.0	98	10.3	94	11.0	94	12.4	84
11	Manchu in basement	10.2	100	10.6	92	11.5	95	10.2	87
12	Midwest in basement	13.2	97	14.1	94	13.9	87	12.8	72
13	Manchu in warm laboratory	6.8	88	7.4	90	9.3	98	7.3	55
14	Midwest in warm laboratory	9.6	93	8.4	96	9.4	86	8.2	45

CROP OF 1924

Seasonal conditions were favorable in 1924 for harvesting the soybean crop. The Manchu, an early variety, and the Midwest, a late variety, both commonly grown by farmers, were selected for the storage experiments. The beans of the Manchu variety were badly damaged in threshing. Approximately one-third of them were removed by a fanning mill. Thirty per cent of those that remained were injured, but in such a way that they could not be mechanically separated from the rest.

Series A

A series of experiments in storing was planned in which each of two varieties was stored as follows: (a) In burlap bags, (b) in cotton bags, (c) in open metal tanks, (d) in closed metal tanks, (e) in wire screen containers, (f) in open tanks in a basement, and (g) in open tanks in a warm laboratory.

Table 1 gives the results, showing the water content and germination tests at different intervals. Although tests were made monthly, the data presented here include only those made at certain intervals which serve to show the trends.

The percentage of germination of the beans under all conditions of storage remained high for more than two years, or until February, 1927, when it began to decline. The test of March 10, 1927, showed a decided loss of vitality in all lots, the greatest decrease being in the beans of both varieties stored in the warm laboratory. As between the two varieties there appears to be a tendency for the Midwest to retain slightly more water than the Manchu. As might be expected, the water content remained consistently lower in those lots stored in the warm laboratory.

Series B

Another set of tests was planned in which the water content of a quantity of each of the two varieties was raised by frequent spraying. In this condition they were subjected to a temperature of —29°C and were frozen solid. After thawing out, they were stored on January 3, 1925, as follows: (a) in open tank, (b) in closed tank, (c) in burlap bags, (d) in cotton bags, and (e) in small closed containers at a temperature of —8°C. Table 2 gives the results of tests made with these beans.

Although these beans had a high water content and had been subjected to a very low temperature, they continued to show a high degree of vitality until the warm weather of spring set in, when the percentage of germination began to decrease. On October 12, 1925, the beans kept in closed containers failed to germinate. Those kept in bags showed decreasing vitality until July 20, 1926, when they failed to germinate. Thus, it appears that ventilation was a critical factor in preserving life in these seeds. The Midwests kept in the open tank were dead on July 20, 1926, but the Manchus continued to show vitality for several months longer.

Series C

A further set of experiments with the beans of the 1924 crop was carried out two years later in which seed was subjected to storage

TABLE 2.—*Water content and percentage of germination of soybeans, stored in different ways after artificially moistening and subjecting to freezing, Series B, crop of 1924.*

Lot No.	Variety and manner of storage	Jan. 10, 1925 Water %	Jan. 10, 1925 Germination %	May 2, 1925 Water %	May 2, 1925 Germination %	Oct. 12, 1925 Water %	Oct. 12, 1925 Germination %	March 13, 1926 Water %	March 13, 1926 Germination %	July 20, 1926 Water %	July 20, 1926 Germination %
15	Manchu in cotton bag	20.4	95	14.1	86	10.5	38	11.8	25	10.0	0
16	Midwest in cotton bag	25.5	95	19.5	82	10.0	36	11.7	29	11.3	0
17	Manchu in burlap bag	20.4	91	13.5	62	9.4	50	12.1	6	10.0	0
18	Midwest in burlap bag	22.3	92	17.5	89	10.6	52	12.3	17	11.8	0
19	Manchu in closed tank	19.4	92	18.8	75	21.4	0	—	—	—	—
20	Midwest in closed tank	23.2	98	19.8	77	18.3	0	—	—	—	—
21	Manchu in open tank	21.4	96	15.1	70	10.5	64	13.1	16	12.0	28
22	Midwest in open tank	22.2	86	19.8	90	12.8	34	10.7	33	14.7	0
23	Manchu at —8 C	19.4	100	—	100	—	—	—	—	—	—
24	Midwest at —8 C	21.8	100	—	84	—	—	—	—	—	—

under various controlled temperature conditions. For this purpose, a few quarts were taken from each of several of the lots of Manchu and Midwest soybeans stored in 1924. Water was added at intervals, the beans thoroughly mixed, and then placed in closed garbage cans until imbibition had taken place. Water tests were made after each addition. In this way, small lots were obtained having water contents as follows:

Lot No.	*Manchu* %	*Midwest* %
1	12.0	11.2
	12.0	11.2
2	13.5	14.2
	13.2	14.2
3	15.2	16.0
	15.2	16.0
4	16.6	18.0
	16.7	18.0

On November 4, 1926, each of these lots was divided into three parts and placed in half-gallon fruit jars. The jars were so arranged as to permit the entrance of air but greatly to retard the escape of moisture. A set of four of these jars with moisture content as indicated was placed in each of three thermostats maintained at constant temperatures of 10°, 20°, and 30°C, respectively. At intervals of one month, samples were taken for germination tests. A miniature sampler resembling the ordinary grain probe was made for the purpose of taking beans from all parts of the containers with as little disturbance as possible.

Small quantities of each of these lots were placed in tightly closed containers in a refrigerating chamber where the temperature was —8°C.

Table 3 shows the results of these tests.

As previously pointed out, the beans used in this experiment were of the 1924 crop. All the previous work with these beans indicated that in February, 1927, they were beginning to decline in vitality. (See Table 1.) An examination of Table 3 discloses further evidence on this point. The beans stored at —8°C declined markedly, while seed taken from the same lots in 1924 and stored in the same place maintained their vitality until May 8, even with a much higher water content. (See Table 4.)

The consistent decline in vitality, accompanying rising temperature and increasing water content, is strikingly brought out by the data of Table 3.

TABLE 3.—*Water content and percentage of germination of soybeans stored in thermostats maintained at 10°, 20°, and 30° C after artificially moistening and subjecting to freezing, Series C, crop of 1924.*

Sample No.	Variety	Initial water content, %	Percentage germination Dec. 6, 1926	Jan. 4, 1927	Feb. 4, 1927	Mar. 4, 1927	Final water content, %
			Soybeans Stored at 10° C				
1	Manchu	12.0	90	95	84	75	11.7
	Midwest	11.2	88	90	76	78	12.3
2	Manchu	13.3	91	90	57	66	12.7
	Midwest	14.2	93	74	65	59	15.0
3	Manchu	15.2	91	84	42	42	16.0
	Midwest	16.0	95	76	71	51	16.5
4	Manchu	16 6	93	86	27	42	15.7
	Midwest	18.0	89	71	47	40	17.7
			Soybeans Stored at 20° C				
1	Manchu	12.0	92	97	73	56	11.5
	Midwest	11.2	92	93	70	57	11.0
2	Manchu	13.3	92	78	25	35	11.6
	Midwest	14.2	83	82	41	33	14.0
3	Manchu	15.2	91	73	14	7	14.5
	Midwest	16.0	84	60	19	8	15.3
4	Manchu	16.6	83	69	19	9	16.0
	Midwest	18.0	66	38	12	4	17.1
			Soybeans Stored at 30° C				
1	Manchu	12.0	92	88	29	29	10.2
	Midwest	11.2	89	94	27	26	10.2
2	Manchu	13.3	87	70	4	3	11.2
	Midwest	14.2	68	16	1	0	13.0
3	Manchu	15.2	52	5	0	0	14 5
	Midwest	16.0	24	6	0	0	15.0
4	Manchu	16.6	52	3	0	0	16.0
	Midwest	18.0	17	3	0	0	16.5
			Soybeans Stored at —8° C				
1	Manchu	12.0	95	—	—	77	—
	Midwest	11.2	93	—	—	74	—
2	Manchu	13.3	95	—	—	82	—
	Midwest	14.2	90	—	—	75	—
3	Manchu	15.2	96	—	—	72	—
	Midwest	16.0	88	—	—	68	—
4	Manchu	16.6	93	—	—	80	—
	Midwest	18.0	87	—	—	74	—

CROP OF 1925

Weather conditions in the fall of 1925 were very unfavorable for the maturing, harvesting, and threshing of soybeans. During the months of September and October, there were 32 cloudy days and 9.85 inches of rainfall as compared with 14 cloudy days and 3.56 inches of rainfall for the same months in 1924. As a consequence the 1925 beans were of a higher water content and a lower vitality than were those of 1924. The experiments with these beans of poor quality from the crop of 1925 are presented in four series of tests.

Series A

Manchu soybeans having a germination of 62 to 64% and a water content of 17.6 to 17.8% were used in this series of tests. These were put into storage the last week in December, 1925, in the manner indicated in Table 4. The water content of the beans of lots 103 and 104 was raised by spraying. These two lots. together with 101 and 102, were placed in an unheated room, while 105 and 106 were put into a room having an almost constant temperature of 27°C. Table 4 shows the water content and germination of these beans.

The water content of the beans in closed tanks remained fairly constant, while in the open tanks it gradually decreased. The effect of lack of ventilation and of a rise of temperature is readily seen in lots 102, 104, and 106, where the tanks were closed. The beans of these lots lost their vitality early, while those of lots 101, 103, and 105, stored in open tanks, continued to germinate well into the warm season or even later.

Series B

The beans in this experiment were also of the Manchu variety and were the best obtainable from the crop of 1925. Forty bushels were put into a bin 4 by 4 by 4 feet in dimensions, filling it to within 10 inches of the top. This part of the experiment is represented by lots 111 and 112. In comparison with these, lot 113 was stored in a sack, and lots 114 and 115 were placed in an open tank and a closed tank, respectively. The water content was raised in lots 116 and 117, after which they were spread out on the floor. Table 5 shows the manner of storage, percentage of germination, and water content of the beans in this series of tests.

The more rapid decline in vitality of the beans in the bottom of the large bin as compared with those of the top is noticeable. Attention is called to the fact that during the hot month of July, the water content of the beans at the bottom reached 17.0%. Those stored in the grain sack kept best, the germination being nearly as high

TABLE 4.—*Water content and percentage of germination of Manchu soybeans stored in different ways, Series A, crop of 1925.*

Lot No.	Manner of storage	Jan. 15, 1926 Water %	Jan. 15, 1926 Germination %	May 1, 1927 Water %	May 1, 1927 Germination %	July 20, 1927 Water %	July 20, 1927 Germination %	Nov. 20, 1927 Water %	Nov. 20, 1927 Germination %	Mar. 10, 1927 Water %	Mar. 10, 1927 Germination %
101	Open tank	16.6	46	15.0	13	13.6	18	13.1	17	14.2	8
102	Closed tank	17.8	31	18.3	20	18.4	0	—	—	—	—
103	Open tank[a]	19.3	30	16.1	23	12.6	53	11.6	12	12.8	2
104	Closed tank[a]	21.1	35	20.5	17	20.0	0	—	—	—	—
105	Open tank at 27°	13.2	32	10.4	50	12.0	27	8.9	0	—	—
106	Closed tank at 27°	18.0	29	15.0	14	15.9	0	—	—	—	—

[a]After preliminary spraying to increase water content.

TABLE 5.—*Water content and percentage of germination of Manchu soybeans stored in different ways, Series B, crop of 1925.*

Lot No.	Method of storage	Feb. 13, 1926 Water %	Feb. 13, 1926 Germination %	April 17, 1926 Water %	April 17, 1926 Germination %	July 20, 1926 Water %	July 20, 1926 Germination %	Oct. 20, 1926 Water %	Oct. 20, 1926 Germination %	March 10, 1927 Water %	March 10, 1927 Germination %
111	Large bin (top)	15.1	92	15.0	85	14.4	89	15.3	65	15.5	45
112	Large bin (bottom)	15.1	92	15.7	88	17.0	88	14.1	44	13.0	25
113	Sack	15.0	91	14.6	89	11.4	72	11.8	88	13.0	84
114	Open tank	15.6	93	19.2	73	12.2	65	16.1	14	13.9	5
115	Closed tank	15.6	93	20.3	68	16.4	0	—	—	—	—
116	Spread on floor	—	—	18.5	83	10.6	65	12.2	76	12.2	40
117	Spread on floor	—	—	22.3	80	10.4	28	12.8	33	11.8	36

at the end as at the beginning of the test. A comparison of lot 114 with 115 still further emphasizes the importance of ventilation in storage.

Series C

Virginia soybeans having a germination of 84% and a water content of 15.1% were used. Lots 121, 122, and 123 were stored without changing the water content, while that of lots 124, 125, and 126 was raised. Table 6 gives the manner of storing each lot and the results of the germination and water determinations.

An examination of Table 6 again brings out the fact that vitality is maintained best when the beans are stored in grain sacks or in open tanks. A comparison of lot 122 with 123 and of lot 124 with 125 shows a loss of vitality due to lack of ventilation. A comparison of lot 122 with 124 and lot 123 with 125 shows the detrimental effect of high water content upon vitality. Lot 126, which was spread in a thin layer upon the floor, maintained a fair germination even though the water content was 19.9% previous to spreading upon the floor. The test of April 17, 1926, indicated a rapid loss of water by these beans which doubtless accounts for their greater longevity.

TABLE 6.—*Percentage of germination and moisture content of Virginia soybeans stored in different ways, Series C, crop of 1925.*

Lot No.	Method of storage	April 17, 1926		July 20, 1926		Oct. 20, 1926		March 10 1927	
		Water	Germination	Water	Germination	Water	Germination	Water	Germination
		%	%	%	%	%	%	%	%
121	Grain sack	15.9	87	12.6	75	13.3	59	12.0	61
122	Open tank	16.5	77	12.6	82	12.3	67	12.3	66
123	Closed tank	16.4	73	15.9	75	17.1	46	14.5	29
124	Open tank	19.2	76	14.0	71	14.1	21	12.6	15
125	Closed tank	21.5	67	19.8	0	—	—	—	—
126	Spread on floor	14.1	70	9.5	56	12.2	49	11.6	53

Series D

Ebony soybeans, in very bad condition when threshed, were used in this experiment. The germination was 65% and the water content 29.0%. These were stored as follows: Lot 131, spread in a layer 3 to 4 inches thick upon the floor of an unheated room; lot 132, recleaned, spread upon the floor of a room having a temperature of approximately 27°C and stirred frequently until the water content was reduced to 14.0%, then placed in grain sacks; lot 133, stored in a large burlap bag; lot 134, stored in an open tank; lot 135, stored in a

closed tank; and lot 136, stored in an open tank in a room with a constant temperature of 27°C. Table 7 shows the results of these tests.

The beans of lot 131, which were spread upon the floor of an unheated room, lost much water and maintained their vitality as a result of this method of handling.

The burlap sack in which the beans of lot 133 were stored was not of the ordinary grain sack dimensions, but was approximately 2 feet in diameter, which partly accounts for the rapid loss of vitality. A comparison of lots 134 and 135 again emphasizes the detrimental effect of a lack of ventilation. Lot 136 was placed in a room having a temperature of 27°C in order to determine in a short time the effect

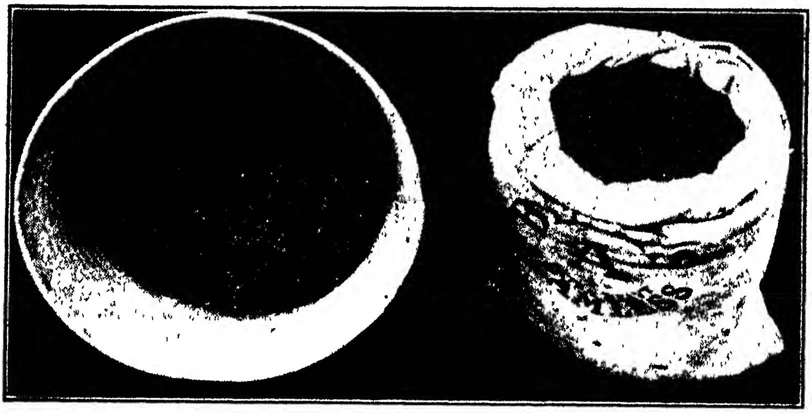

Fig. 1.—Ebony soybeans of lot 132 (right) and lot 133 (left) as they appeared in January, 1927.

of high temperature upon beans in this condition. They became a mouldy, malodorous mass in two weeks. Here again the importance of the proper handling of beans of high water content is made apparent, the effect being most strikingly brought out in a comparison of lots 132 and 133 (Fig. 1).

EFFECT OF THRESHING DAMAGE UPON THE LONGEVITY AND VIGOR OF SOYBEAN SEED

The Manchu soybeans used in the storage work in 1924 were very badly broken in threshing. As many as possible of these broken beans were mechanically removed. Although the recleaned beans had a good appearance, close examination showed that approximately 30% were damaged to some extent.

Much research has been conducted upon the effect of injuries to seeds. A review of the work by Andronescu (2), Brown (6), Duggar

TABLE 7.—*Water content and percentage of germination of Ebony soybeans stored in different ways, Series D, crop of 1925.*

Lot No.	Manner of storage	Feb. 13, 1926		July 20, 1926		Oct. 20, 1926		March 10, 1927	
		Water	Germination	Water	Germination	Water	Germination	Water	Germination
		%	%	%	%	%	%	%	%
131	Spread on floor	18.3	71	11.2	65	13.9	61	12.3	65
132	Dried with heat	17.1	73	10.8	78	11.8	78	12.3	69
133	Burlap bag	26.4	47	15.7	0	—	—	—	—
134	Open tank	18.5	72	15.0	70	14.1	34	14.3	27
135	Closed tank	29.4	50	26.0	0	—	—	—	—
136	Open tank warm room	In two weeks these beans were mouldy and gave off a strong odor of ammonia							

(10), Harrington (14), Graber (12), and others indicates that, while such injuries may not prove detrimental to the seeds if planted immediately, longevity is very seriously affected by injuries so slight as to be imperceptible without the aid of a magnifying glass. Scarified legume seed give a higher percentage of germination if used at once, but their vitality is maintained only a comparatively short time. The threshing machine has an effect similar to scarification.

In some of the above-mentioned investigations the injuries were made artificially. In those reported in this paper they were made in the process of threshing. An attempt was made to classify the beans according to their injuries as follows: (a) No injury; (b) crack in the bean, in many cases scarcely discernible; (c) injury to cotyledons only; (d) injury to germ; (e) small pieces of beans; and (f) hilum completely removed. The last two classes were damaged in such a way as to make it plainly evident that they were valueless for seed purposes. They were not used in the work described herein. Tests were made with the beans in soil in the greenhouse and in sand in the plant physiology laboratory.

INJURED SOYBEANS PLANTED IN OPEN POTS

Two sets were planted in open pots in the greenhouse on February 17, 1925, at the rate of five beans per pot. Set A consisted of beans containing 11.3% of water. Set B consisted of beans that had been sprinkled to increase the water content. At the time of planting, the water content was 18.4%, though it had been 21.4% a month before.

Fig. 2 illustrates the appearance of mature plants produced by seeds No. 1, 2, 3, and 4. An examination of this figure and of Table 8 brings out the following facts.

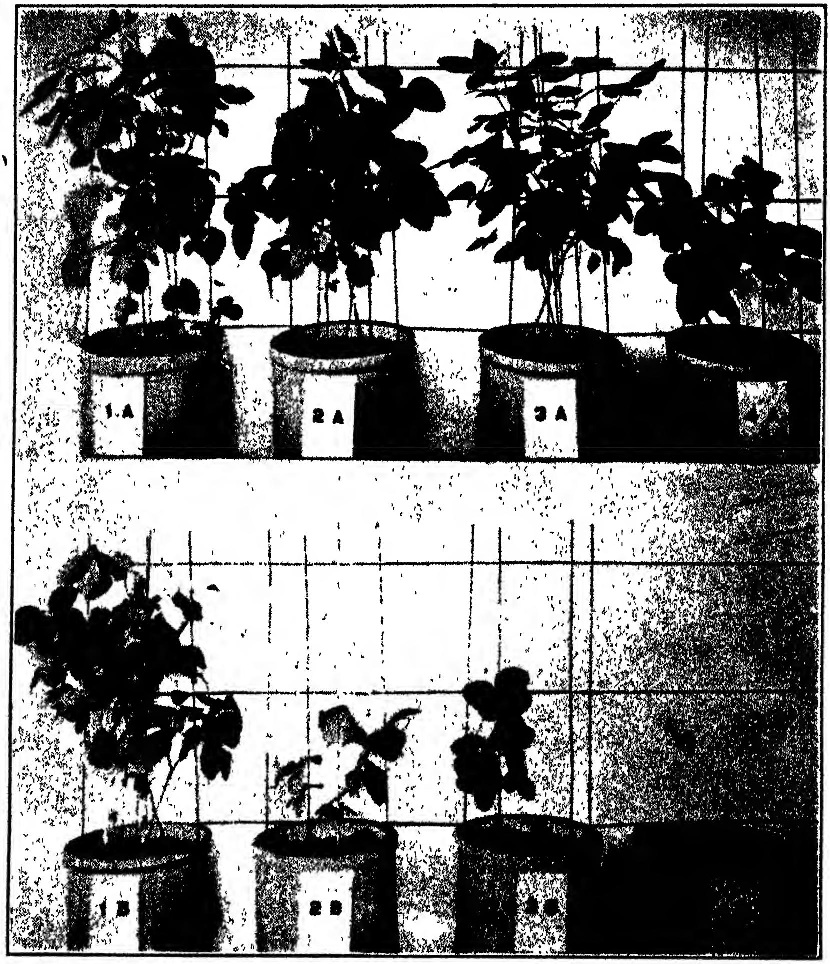

Fig. 2.—Mature plants grown from injured soybeans.

The effect of the injury was not great in set A (normal water content) except in the case of No. 4. Here only one seed out of five grew and the plant was small and weak. In set B, where the seed contained over 18% of water, the effect of mutilation was marked. In the control all five seeds grew; where the injury was represented by a cracked seed only three out of five seeds grew; where the cotyledons were injured two out of five seeds grew; and where the germ

TABLE 8.—*Growth of mutilated soybean seed in open pots.*

Set	Kind of injury	Number of seeds planted	Number of plants emerging
Set A	No. 1 (not injured)	5	5
(water content	No. 2 (beans cracked)	5	5
11.3%)	No. 3 (cotyledon injured)	5	4
	No. 4 (germ injured)	5	1
Set B	No. 1 (not injured)	5	5
(water content	No. 2 (beans cracked)	5	3
18.4%)	No. 3 (cotyledon injured)	5	2
	No. 4 (germ injured)	5	0

received the injury none of the seeds developed. Not only was the effect of mutilation apparent in the germination, but it was reflected in the size and vigor of the plants as well. The deleterious effect of mutilations was evidently brought about largely through the development of moulds, which were noticeable on the injured places in the beans of high water content.

INJURED SOYBEANS PLANTED IN THERMOSTATS

Samples of the same two sets of seed used in the preceding experiments were planted in thermostats under controlled conditions of temperature and moisture. For these experiments a series of temperature chambers was maintained at 10°, 15°, 20°, and 30°C, and in order to vary the moisture in the substratum, the beans were planted in metal boxes in sand held at three different degrees of saturation, namely, 25, 50, and 75%. These moisture conditions were kept practically constant by weighing daily and adding water.

Each box was divided into four sections and five seeds, representing the respective types of injury, were planted in each section as follows: No. 1, not injured; No. 2, beans cracked; No. 3, cotyledons injured; and No. 4, germs injured. Daily measurements were taken on the resulting plants as they developed in order to compare the growth under the various treatments.

Table 9 gives the number of plants produced and the extent of growth as expressed by length of stem under the several different conditions of moisture and temperature for each lot of seed of normal water content (set A), and Table 10 contains the corresponding data for the seed of high water content (set B).

In comparing the results from the different kinds of mutilation marked difference in growth is observed, injury to germ proving most nearly fatal. The condition represented by "cracked beans" proved somewhat more serious than cotyledon injury.

The beans in the 30° thermostat sprouted first, followed in order by those at 20° and those at 15°. The beans in the 10° thermostat failed to come up. Of the four temperatures tried, 30° furnished the optimum for growth.

TABLE 9.—*Growth of mutilated seed of normal water content (set A) under different conditions of temperature and moisture in substratum.*

No.	In 30° thermostat one week after planting: No. of plants	In 30° thermostat one week after planting: Total growth in cm	In 20° thermostat two weeks after planting: No. of plants	In 20° thermostat two weeks after planting: Total growth in cm	In 15° thermostat three weeks after planting: No. of plants	In 15° thermostat three weeks after planting: Total growth in cm
			25% of Saturation			
1	5	200.9	5	177.2	5	82.7
2	5	165.4	5	192.9	3	46.2
3	5	157.5	5	145.6	4	66.9
4	4	70.9	3	43.3	1	3.9
			50% of Saturation			
1	4	159.6	5	173.2	5	78.7
2	5	137.8	3	74.8	4	46.2
3	5	200.9	5	114.2	4	74.8
4	3	59.0	2	11.8	2	—
			75% of Saturation			
1	1	19.7	2	—[a]	2	—[a]
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	1	—[a]	0	0	0	0

[a] These plants failed to make any growth and soon died.

TABLE 10.—*Growth of multilated seed of high water content (set B) under different conditions of temperature and moisture in substratum.*

No.	In 30° thermostat one week after planting: No. of plants	In 30° thermostat one week after planting: Total growth in cm	In 20° thermostat two weeks after planting: No. of plants	In 20° thermostat two weeks after planting: Total growth in cm	In 15° thermostat three weeks after planting: No. of plants	In 15° thermostat three weeks after planting: Total growth in cm
			25% of Saturation			
1	5	137.8	5	122.0	5	92.4
2	4	78.7	4	59.0	3	35.4
3	5	78.7	2	15.7	4	31.5
4	2	15.7	1	—[a]	1	—[a]
			50% of Saturation			
1	5	129.9	5	189.0	5	122.0
2	3	11.8	5	23.6	2	—[a]
3	4	55.1	3	63.0	4	86.6
4	0	0	1	—[a]	1	—[a]
			75% of Saturation			
1	5	137.8	4	82.7	5	161.4
2	2	11.8	3	19.7	4	43.3
3	5	55.1	4	50.2	4	43.3
4	1	—[a]	2	11.8	2	39.4

[a] These plants failed to make any growth and soon died.

With seed at normal water content (Table 9), no great difference was observed as to whether the substratum was maintained at 25% water saturation or at 50%. At 75% saturation, however, the result was nearly fatal. Here only 6 seeds sprouted out of the 60 planted and of these all but one soon died without making any appreciable growth. With seed of high water content (Table 10) the 75% saturation does not appear so unfavorable. In fact, in the low temperature chamber (15°), the high saturation seemed to be positively favorable to growth.

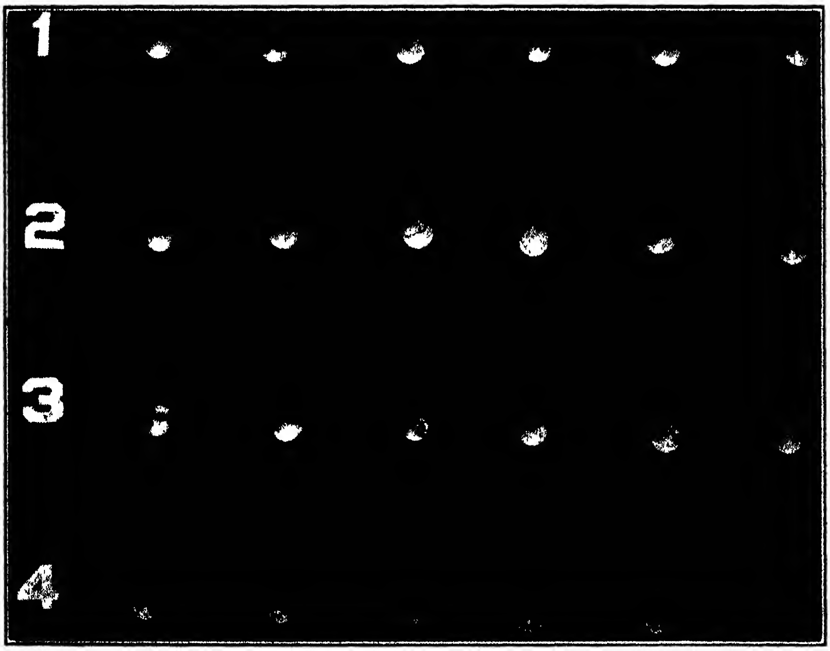

Fig. 3.—Classes of injured soybeans.

Samples of these beans were tested for germination from time to time and a striking difference in longevity between injured and uninjured seed was revealed. On November 8, 1926, the average germination of the injured seed of normal water content was only 16% as compared with 95 to 96% for uninjured beans from the same lot. Fig. 3 shows the different types of seed injury described. The beans illustrated were placed in the germinator just as they appear in the photograph. Fig. 4 shows their appearance five days later. An examination of Fig. 4 shows that an injured bean, the fifth in row 1, passed the examination as an uninjured seed.

The growth of moulds starting at the injured places is very striking. Doubtless the loss of vitality is largely due to penetration of micro-organisms at these points. Myers (18), in his work with broken pericarps of corn, found the first evidence of moulds at breaks in the pericarp. Hurd (15) found the same to be true with regard to wheat. Melhus and Durrel (17), in their work with Diplodia, found that these diseases "usually attack the kernel through some crack, as a

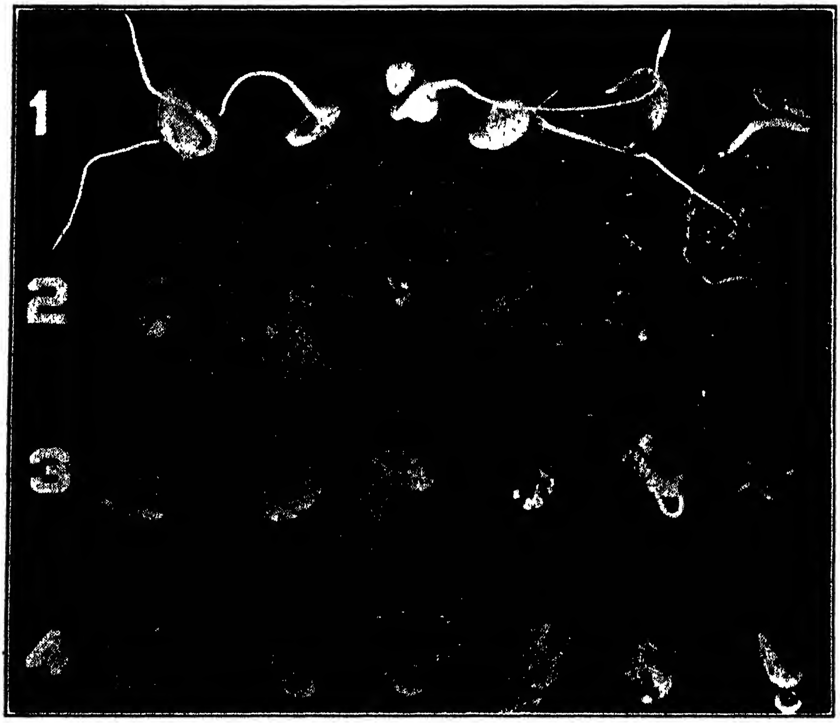

Fig. 4.—Injured soybeans of Fig. 3 after five days in the germinator.

broken tip, or where the kernel was scratched when removed from the ear. These moulds, in many cases, injure the germination or kill the young shoots and roots."

SUMMARY

Soybeans of the crops of 1924 and 1925 were stored in many ways and under different conditions of heat, water content, and ventilation. The weather conditions which prevailed during the months of September and October of these years had a distinct effect upon the water content, germination, and longevity of the soybeans. The

conditions were ideal in 1924 for maturing, harvesting, and threshing, while in 1925, they were such as to make it difficult to secure good seed for experimental purposes.

Whatever the water content at the beginning of storage, a percentage ranging from 10 to 14 was generally reached and maintained by the beans in storage if there was opportunity for ventilation. This might be considered as the normal water content of soybeans in this region.

The soybeans which did not at any time appreciably exceed this water content maintained their vitality unimpaired for more than two years, regardless of conditions under which they were stored. The vigor of germination in all tests made at the time of the second seeding period after their production indicated that these beans were in excellent condition for seed purposes.

When the water content of any of the soybeans used in these storage tests appreciably exceeded 14%, ventilation and heat proved to be critical factors affecting their longevity. This was shown by the beans of the 1925 crop which declined in vitality very distinctly, except where provision was made for abundant circulation of air and a quick reduction of water content.

Manchu soybeans of the 1925 crop, having a water content of 15.0% and a germination of 92%, and stored in a bin, maintained their viability unimpaired in the top and in the bottom of the bin until after the seeding season of 1926. The tests of October 20, 1926, and subsequent dates showed a distinct decline in germination, which was much more marked in the bottom than in the top of the bin. The test of March 10, 1927, showed that, with the exception of those stored in a sack with abundant provision for circulation of air, all of the Manchu beans of this lot had suffered such a decline in viability as to render them unfit for seed purposes on that date. The germination of those stored in a sack showed only a slight decline, which was probably not significant. Beans of this same lot in which the moisture content was raised to 20 to 22% declined in viability even though spread in a thin layer upon the floor.

Soybeans of high vigor and vitality and with a moisture content of 25.5% withstood a temperature of —29°C for a day and were stored in small quantities for four months at a temperature of —8°C without impairment of vitality. Warm spring and summer temperature brought about a rapid decline.

When the high moisture content of the 1925 crop was reduced to normal before the advent of warm temperatures of spring, the beans maintained their vitality unimpaired to the end of this experiment, March 10, 1927.

The Manchu soybeans stored in 1924 were badly damaged in threshing. After they were well recleaned, there still remained about 30% of injured beans. In many cases the damage was discernible only upon close examination.

The effect of the injury to the seed upon the number of plants produced was very pronounced. The effect upon the growth of the plants after germination was not marked in the case of beans of normal moisture content. In those of high moisture content it was very marked.

Micro-organisms attacked the beans at the injured places.

Vitality decreased more rapidly in the injured than in the uninjured beans.

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EFFECT OF THE CONTINUOUS SELECTION OF LARGE AND SMALL WHEAT SEED ON YIELD, BUSHEL WEIGHT, VARIETAL PURITY, AND LOOSE SMUT INFECTION[1]

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A varietal comparison of any crop presupposes that the varieties are definite. With many crops, especially those propagated by seeds, there is opportunity for the mechanical mixing of varieties in seeding, harvesting, threshing, and cleaning. There exists, furthermore, in such crops as the more important small grains, the chance for a varying degree of mixing of varieties by natural crossing. Roguing serves to maintain varietal type, though not necessarily varietal purity.

In wheat those off types which differ from the variety in such outstanding spike characters as color or covering of chaff, shape of head, or awnedness, usually are recognized and removed at roguing time. Mixtures between varieties with similar spike characters and mixtures due to natural crossing between similar varieties and the following segregation probably are generally unrecognized. For example, a mixture of the wheat varieties Purplestraw and Fultz would escape the average roguing as both are awnless, with white glabrous chaff, yet they are distinct as the reaction of Purplestraw when spring sown is that of a spring wheat, whereas the reaction of Fultz when spring sown is that of a typical winter wheat. It is probable that the older varieties, as Purplestraw, Fulcaster, and Fultz, grown in the varietal experiments at the Arlington Experiment Farm near Washington, D.C., are in reality each a composite variety composed of strains of one general and apparently high-yielding type. As the origin of the strains making up the variety probably is due to natural crossing and some mechanical mixing, it is possible that the Arlington varieties, when compared for yield or physiological or pathological reactions, would respond differently from varieties with the same name from other sources, particularly from stations where varietal experiments are conducted. Stadler[3] found that different strains of certain wheat and oat varieties obtained from different sources showed decided variability in their yield performance.

[1]Contribution from Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication May 24, 1928.

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[3]STADLER, L. J. An experimental study of the variety as an agronomic unit in wheat and oats. Jour. Amer. Soc. Agron., 16:366-372. 1924.

Certain routine practices used in conducting a varietal experiment may increase or decrease the amount of mixing, including that due to natural crossing. It had been the practice at the Arlington Experiment Farm to fan and screen for large size all seed wheat used in the varietal experiments. In the course of these experiments it has been noted that the three varieties, Kanred, Nebraska No. 28, and Purplestraw, usually contain many off-type plants. When tested the majority of these were found to be natural hybrids. All three of these varieties are small kernelled, and it was believed that the sorting out and seeding of the larger kernels increased the mixture, especially of large-kernelled strains. Purplestraw, a high-yielding variety in parts of the southeastern United States, would be more generally grown if the kernels were of larger size, as the growers object to the relatively small kernels compared with the larger ones of Leap or Fulcaster.

Experiments were begun in 1921 with the variety Purplestraw to observe any effects the use of large and small seed would have upon varietal type or performance. It was desired, also, to obtain, if possible, by a form of mass selection a strain retaining the high-yielding ability of Purplestraw but possessing larger kernels. The purpose of this paper is to report the principal results obtained in the six-year period, 1922 to 1927, inclusive, on the continuous annual selection of large and small seed of this variety.

MATERIALS AND METHODS

The variety Purplestraw is a soft red wheat grown commercially from fall seeding in the southeastern part of the United States. According to Clark, Martin, and Ball,[4] the origin of Purplestraw is undetermined, but it is one of the oldest varieties of wheat grown in the United States, its known cultivation dating back to 1822. Purplestraw is an awnless, white, glabrous chaffed wheat possessing apical awns varying in length from 3 to 10 mm. The Arlington strain of Purplestraw grown in the varietal experiments since 1910 apparently is typical of the variety.

Two 40th-acre plats of Purplestraw in the 1921 varietal experiment, each of which was located between a 20th-acre plat of Abruzzes rye and a 40th-acre plat of Fulcaster (Bearded Purplestraw) wheat, were carefully rogued, harvested, and threshed. The threshing of these original seed plats, as well as all plats in the experiment on seed size, during the following years of the experiment was done

[4]Clark, J. Allen, Martin, John H., and Ball, Carleton R. Classification of American wheat varieties. U. S. D. A. Bul. 1074. 1922.

before the threshing of the different wheat varieties in the varietal experiment in order to reduce the opportunity for mechanical mixtures. The grain from the two 1921 plats of Purplestraw was mixed and graded for size by means of a Hero fanning mill fitted with a wire-bottomed screen having a mesh 15½ x 2 2/9 mm. The grain passing over the screen is called large seed in this paper and that passing through the screen is called small seed. There was three times as much small seed as large in the 1921 Purplestraw wheat.

The small seed sown in the following years was obtained from that portion of the preceding crop from the small-seed plats which passed through the screen just described. The large seed sown was obtained annually from the grain of the preceding crop from the large-seed plats which passed over the screen.

Fortieth-acre plats (132 x 8.25 feet) were used from 1922 to 1925, inclusive, and approximately 96th-acre plats (132 x 3.44 feet) were used in 1926 and 1927. The plats sown with large and small seed were alternated, and in all years but 1923 the experiment was conducted on one parcel of land. In 1923, two small parcels were used. The number of plats of each seed size grown annually varied from three in 1927 to eight in 1925, as may be seen in Table 1.

The seeding rates used in 1922 and 1923 were 5 pecks per acre for the small seed and 6 pecks for the large. These rates gave an average fall stand of 22.8 plants per foot from the large seed and 30 plants per foot from the small. The seeding rate used in 1924 and later years for the small seed was 4½ pecks which produced approximately the same stand as the 6-peck rate used for the large seed.

EXPERIMENTAL DATA

GRAIN YIELD

Table 1 gives the annual plat yields in bushels per acre and the weight per bushel in pounds for each of the six years of the experiment. The data in Table 1, reading from left to right and from top to bottom, are arranged in the order of the plats in the field, with the exception of 1922 and the last four plats of 1923. In 1922 the series began with a small-seed plat yielding at the rate of 37.1 bushels, and in 1923 the last four plats were grown on a different parcel of ground from the preceding plats and began with the small-seed plat yielding at the rate of 26.5 bushels. Table 2 contains the average data and also the odds of the significance of the differences obtained, as calculated by Student's method.

Large seed outyielded small seed in five of the six years of the experiment and especially so in the last two years, when high yields

TABLE 1.—*Individual and annual average yields of grain in bushels per acre and bushel weights of grain in pounds obtained from large and small seed of Purple-straw wheat in plats variously replicated in the six-year period, 1922-1927, inclusive.*

Year	Large seed: Grain yield in bushels	Large seed: Bushel weight in pounds	Small seed: Grain yield in bushels	Small seed: Bushel weight in pounds
1922	32.8	61.0	37.1	61.0
	29.0	61.0	30.8	61.0
	32.1	61.0	29.3	60.5
	32.1	62.0	37.3	60.0
	25.3	62.0	26.3	61.5
	30.5	62.5	26.6	61.0
	27.8	61.0	26.6	61.5
Average	29.9	61.5	30.6	60.9
1923	36.7	60.3	36.3	60.0
	37.6	60.0	32.0	60.0
	33.7	59.3	27.9	60.0
	26.0	60.0	26.5	61.0
	29.5	60.8	29.3	60.8
Average	32.7	60.1	30.4	60.4
1924	32.3	58.5	31.5	59.0
	35.5	60.0	37.9	57.5
	40.6	58.5	39.1	57.0
	34.3	58.0	34.0	57.0
Average	35.7	58.8	35.6	57.6
1925	32.2	61.5	30.1	62.0
	21.9	62.5	18.1	62.0
	21.6	63.0	22.2	62.0
	22.0	62.0	18.0	62.5
	17.3	61.5	17.3	62.0
	17.3	62.5	15.3	62.0
	16.8	62.0	15.5	62.0
	15.7	62.0	14.4	62.0
Average	20.6	62.1	18.9	62.1
1926	41.6	62.0	35.4	63.0
	47.4	63.0	40.0	62.0
	45.6	62.5	40.5	62.0
	44.3	62.5	36.5	62.0
	37.3	62.0	29.8	61.5
Average	43.2	62.4	36.4	62.1
1927	47.0	62.0	42.6	60.5
	49.6	60.5	40.0	61.0
	48.0	61.5	41.4	60.5
Average	48.2	61.3	41.3	60.7

were obtained. The gain in yield of large seed over small in 1926 was approximately 19%, and in 1927 it was approximately 17%. The odds are significant in both years.

TABLE 2.—*Average annual yields in bushels per acre and average bushel weights in pounds from all plats of Purplestraw wheat sown with large and with small seed, respectively, and the mathematical significance of the gain or loss.*

Year	Grain yield, bushels per acre: Large seed	Grain yield, bushels per acre: Small seed	Gain or loss in bushels per acre of large seed in comparison to small	Odds as to significance of gain or loss	Bushel weight in pounds: Large seed	Bushel weight in pounds: Small seed	Gain or loss in pounds of large seed in comparison to small	Odds as to significance of gain or loss
1922	29.9	30.6	—0.7	2.3:1	61.5	60.9	+0.6	13.4:1
1923	32.7	30.4	+2.3	10.4:1	60.1	60.4	—0.3	5.3:1
1924	35.7	35.6	+0.1	1.1:1	58.8	57.6	+1.2	10.8:1
1925	20.6	18.9	+1.7	102.1:1	62.1	62.1	——	——
1926	43.2	36.4	+6.8	9999:1	62.4	62.1	+0.3	3.7:1
1927	48.2	41.3	+6.9	43.4:1	61.3	60.7	+0.6	4.2:1

BUSHEL WEIGHT OF GRAIN

In 1923 the crop produced from the small seed had a higher bushel weight than that from the large seed, although the 0.3 pound per bushel difference has no mathematical significance. In 1925 there was no real difference in the bushel weight of the crops produced from large and from small seed. In the remaining four years increased bushel weights resulted from using large seed, the gains ranging from 0.6 pound per bushel in 1922 and 1927 to 1.2 pounds in 1924. In none of the six years was the gain or loss significant as tested by Student's method.

PERCENTAGE OF LARGE AND SMALL KERNELS PRODUCED BY CROPS FROM LARGE AND SMALL SEED

Data were obtained on the percentage of large and small kernels in the grain produced from the large and the small seed sown the preceding fall, beginning with the crop of 1923. The separation for seed size was made by means of the screen of the Hero mill. As noted previously, large kernels are those which passed over and small kernels are those which passed through the screen with a mesh 15½ x 2 2/9 mm. The percentages of large seed in the crops from the plats sown with large and with small seed are given in Table 3. The variation in individual plat percentages of large seed in the crops

grown from the large and from the small seed is large. It is evident, however, that large seed produced a greater percentage of large kernels in all five years. The ratios of the percentages of large kernels in the crop from small seed as compared to that from the large seed are as follows: In 1923, 1:1.6; in 1924, 1:1.8; in 1925, 1:1.9; in 1926, 1:2.7; and in 1927, 1:2.2.

It is probable that the continuous selection of large and small seeds separated strains of different kernel size, some of which no doubt were similar to Purplestraw in appearance. Several of these strains were probably present in the original seed lot in 1921, and others may have been produced later by natural crossing. In addition, seeds which were of small size because of disease probably would produce smaller kernels than the large healthy seeds. Seeds of small size, due to chance, such as location on the spike or spikelet, would give the seedling a poorer start than that given by the larger kernel. Those seedlings with a poorer start probably would never make as vigorous plants on the average or produce as large seeds as the seedlings from larger seeds.

TABLE 3.—*Percentage of large kernels in adjoining plats grown from continuously selected large and small seed wheat for the five-year period, 1923-1927, inclusive.*

Year	Percentage of large kernels in plats grown from continuously selected: Large seed	Small seed	Average annual percentage of large kernels in plats from: Large seed	Small seed	Ratio of large to small
1923	35.5	22.6			
	22.7	14.2	29.1	18.4	1:1.6
1924	25.6	13.1			
	20.2	9.0			
	21.3	16.7			
	25.2	—	23.1	12.9	1:1.8
1925	43.1	23.9			
	35.0	27.0			
	23.0	10.1			
	34.0	12.8			
	36.9	30.6			
	44.4	8.7			
	28.8	—	35.0	18.9	1:1.9
1926	32.3	8.1			
	36.5	9.1			
	35.0	18.4			
	34.2	15.6	34.5	12.8	1:2.7
1927	54.1	17.1			
	59.0	28.5			
	63.7	35.7	58.9	27.1	1:2.2
Average	35.5	17.8			

DISTRIBUTION OF F_1 WHEAT-RYE HYBRIDS IN LARGE, SMALL, AND UNSORTED SEED

Every year some wheat flowers are fertilized by rye pollen at the Arlington Experiment Farm. The F_1 hybrid plant is readily recognized when present in the wheat plats by its taller growth, intermediacy between the two parents in spike characters, almost total sterility, and usually by the "hairy-neck" character of the rye parent. The original Purplestraw seed in 1921 was from plats grown adjacent to Abruzzes rye and ample opportunity for natural crossing had existed. In 1922 the plats sown with large and small seed were from 40 to 150 feet distant from rye, and in the remaining years of the experiment their distance from rye was from approximately 200 to 380 feet.

The data given in Table 4 show the number of F_1 wheat-rye hybrids in the plats from large and from small seed for the years 1922 and 1923. Data for 1922 also include the number of these hybrids in the varietal plats grown from seed of Purplestraw wheat which received no sorting for size of grain in 1921, excepting what may have occurred from the fan of the threshing machine. The varietal plats were located close to rye in 1921. In addition to the number of wheat-rye hybrids in the check plats in 1923, the number of wheat-rye hybrids present in what is called extra small seed is given in Table 4.

TABLE 4.—*Number of F_1 wheat-rye hvdrids in 40th-acre plats sown with large, small, and unsorted seed, and in extra small seed of Purplestraw wheat in 1922 and 1923.*

Sort of seed	Number of F_1 wheat-rye hybrids in each of seven 40th-acre plats in 1922 and 1923 sown with large and small seed							Total number of plats of each seed sort	Total number of wheat-rye hybrids observed	Average number of wheat-rye hybrids per plat
						1922				
Large	0	0	0	1	0	0	0	7	1	0.1
Small	14	19	21	23	18	21	16	7	132	18.9
Unsorted								101	100	1.0
						1923				
Large	0	1	0	0	0	1	0	7	2	0.3
Small	2	3	5	2	3	11	14	7	40	5.7
Unsorted [a]								110	2	0.02
Extra small seed								2	41	20.5

[a] In 1923 the extra small seed was taken from this unsorted seed. The extra small seed constituted 1.75% by weight of the total unsorted seed.

The extra small seed was that portion of the grain screened from the seed used for the 1923 check plats, which was obtained by reducing the speed of the fan of the Ellis Keystone No. 2 thresher and re-

placing the blank with a screen having 8 meshes to the inch. The kernels passing through this screen were collected and called extra small seed.

Screening for seed size automatically puts the wheat-rye hybrid kernels into the small-seed portions. In the crop of 1922 there was an average of about 19 F_1 wheat-rye hybrid plants in each 40th-acre plat sown with small seed as compared to an average of 0.1 plant in each plat sown with large seed. The plats sown with unsorted seed averaged 1 wheat-rye hybrid plant per plat. The number of wheat-rye hybrids present in the experimental plats in 1923 was much less, yet an average of approximately 6 hybrid plants was found in each of seven small-seed plats as compared to an average of 0.3 hybrid plant in the large-seed plats. Only 2 wheat-rye hybrids were observed in 110 40th-acre plats from Purplestraw seed in 1923, but an average of 21 wheat-rye hybrids were present in each of two 40th-acre plats grown from the extra small seed of this Purplestraw seed. The hybrid wheat-rye kernel usually is shrivelled or of scant endosperm development, as is shown by the sorting of the hybrid kernels into the small-seed lots. Many of these hybrid seeds fail to germinate or to produce mature plants. This is well illustrated in the wheat-rye studies conducted at Arlington on a strain of wheat that has been isolated and is very similar to Purplestraw in plant and spike characters. In this wheat a five-year average of 30% of the flowers artificially pollinated with rye pollen have produced hybrid kernels. The endosperm development of these kernels has been poor. Only 18% of field germination was obtained from 313 kernels resulting from the pollination of this Purplestraw strain with rye in 1926. Greenhouse germination of kernels from the same cross, however, was 65%. Although 318 wheat-rye hybrids were present in the 241 plats of Purplestraw wheat grown at Arlington Farm in 1922 and 1923, many more wheat flowers undoubtedly were fertilized with wheat pollen than the number of hybrids present would indicate.

Furthermore, it is probable that a great many more wheat flowers were pollinated by rye than were fertilized with rye pollen. In 1924 and 1925, a total of 1,214 Purplestraw wheat flowers artificially pollinated in the greenhouse with pollen from five varieties of rye produced only 9 kernels. The relative incompatibility of this variety to hybridization with rye thus shown would indicate that in 1921 and 1922 the pollination of Purplestraw flowers with rye was very general.

BEARDED ROGUES PRESENT IN PLATS FROM LARGE AND FROM SMALL SEED

No data on wheat rogues in the large-seed and small-seed plats were taken in 1922 and 1923. In 1923, it was first observed that more

fully awned spikes were present in the plats sown with large seed than in those sown with small seed. Data were recorded, therefore, in the following years and are given in Table 5 for the four-year period, 1924–1927, inclusive. The data given are the average numbers of bearded heads per row obtained by counts in the two outside rows of each plat. Fully awned types are readily distinguished in the awnless Purplestraw variety. Other wheat rogues have not been especially noticeable in plats from either sort of seed.

In 1924 there were 13 times as many bearded heads in the outside rows of the plats sown with large seed as there were in those sown with small seed; in 1925 there were 27 times as many; in 1926 there were 36 times as many; and in 1927 there were 64 times as many. In 1927, a check plat of Purplestraw grown from unsorted seed of the varietal test contained an average of 6 bearded heads to each border row as compared to the averages of 2.7 and 174 for small-seed and large-seed plats, respectively.

TABLE 5.—*Comparative numbers of bearded heads and loose-smutted heads occurring in plats sown with continuously selected large and small seed of Purplestraw wheat.*

Year	Average number of bearded heads in each outside row of plats sown with		Average number of loose-smutted heads in each 96th-acre plat sown with	
	Small seed	Large seed	Small seed	Large seed
1924	4	52	—	—
1925	1.6	43.9	—	—
1926	1.9	67.6	7.8	2.6
1927	2.7	174	67.3	12.7

The presence and increase of the bearded rogues in the plats from large seed may possibly be due to overlooking bearded heads in roguing the 1921 seed plats, or to mechanical mixture previous to the 1924 harvest with a bearded white-chaffed type with larger seed than Purplestraw. The bearded forms, however, are too variable in maturity and beak character to be classed as Fulcaster which they resemble most nearly. To obtain further data on the appearance of the bearded type in plats sown with large seed, a plat of Purplestraw was sown in 1923 with seed that had been grown for two years without fanning. The plat adjoined a plat of Mammoth Red, a bearded, large-kernelled type. The 1924 plat of Purplestraw was carefully rogued, harvested, and threshed. The grain from this plat was sorted into lots of large and small seed and a 40th-acre plat was grown from each in 1925. A few bearded heads were present in both

plats and were removed. In 1926, a 96th-acre plat sown with the large seed separated from the grain produced in 1925 on the large-seed plat contained 51 bearded heads, in comparison with 4 bearded heads in a similar plat sown with small seed separated from the grain produced in 1925 on the small-seed plat.

The observed frequency of natural hybrids between wheat varieties grown in proximity to each other makes it appear probable that natural crossing has been a major factor in the occurrence of the bearded rogues. The original 1921 lot of Purplestraw no doubt contained at least several similar wheat strains mostly of the awnless, white-chaffed type some of which were of different kernel size, and in addition, possibly a few forms heterozygous for awn development, which are not readily recognized in a tip-awned variety of the Purplestraw type. It is probable that as much or more natural crossing occurred in 1921 between Purplestraw and Fulcaster wheats than between Purplestraw and Abruzzes rye.

The natural crossing occurring between Purplestraw and Fulcaster wheats would probably result in a hybrid kernel fully as large as, or of larger size than, that of Purplestraw and one which would germinate at least fully as well. Griffee[5] found that the average weight of intervarietal hybrid kernels of three *Triticum vulgare* crosses was approximately 24 to 60% greater than the weight of kernels produced by selfing the female parents. Screening the grain from the 1921 seed plats of Purplestraw for kernel size may have sorted the majority of the hybrid kernels of the cross Purplestraw x Fulcaster into the lot of large seed. The later screening of the grain from the large-seed plats for large kernel size would tend to save the segregates of large kernel size, some of which would be fully awned like the Fulcaster parent.

OCCURRENCE OF LOOSE SMUT IN THE PLATS FROM LARGE AND SMALL SEED

The more common plant diseases affecting wheat at the Arlington Experiment Farm are leaf rust (*Puccinia triticina* Erikss.), Septoria, and loose smut (*Ustilago nuda* Pers.). No measurable differences in the prevalence of either of the two former diseases in the large-seed and small-seed plats were observed. Loose smut seldom exceeds 2% of infection in any variety as determined by head counts, though as high as 8% has been observed in the variety Harvest Queen in one year. Usually, a trace of loose smut is recorded annually in the variety Purplestraw.

[5]Griffee, F. Comparative vigor of F_1 wheat crosses and their parents. Jour. Agr. Res., 22:53–63. 1921.

In two years of the experiment, 1926 and 1927, the number of loose-smutted heads present in each 96th-acre plat grown from large seed and small seed was recorded. The data recorded in Table 5 show that in 1926 an average of 7.8 loose-smutted heads occurred in each such plat sown with small seed in comparison with an average of 2.6 loose-smutted heads in each plat sown with large seed. More loose smut occurred in 1927, an average of 67.3 loose-smutted heads being present in each 96th-acre plat sown with small seed in comparison with an average of 12.7 loose-smutted heads in each plat sown with large seed. A 40th-acre plat of Purplestraw from unsorted seed of the 1926 crop grown near the first large-seed plat contained the equivalent of 17 heads infected with loose smut to the 96th-acre. A possible explanation of the larger percentages of loose smut in the plats from small seed is that the presence of the loose-smut organism, which enters at flowering time, checks the development of the endosperm of the wheat kernel, and a kernel of reduced size results.

SUMMARY

The experiments described in this paper were undertaken to show the effect of continuous selection of large or small seed wheat of a small-kernelled variety on varietal purity and behavior. Purplestraw wheat was grown in 1921 between plats of Abruzzes rye and Fulcaster (Bearded Purplestraw) wheat and the resulting crop of Purplestraw seed was sorted into large and small sizes. In the following years of the experiment the large seed was sorted annually from the crop of the large-seed plats of the previous harvest and the small seed from the crop of the small-seed plats.

Increased grain yields were obtained in all years but the first from the use of large wheat kernels. The gains from using large seed in comparison with small seed varied from approximately 0.3% in 1924 to 18.7% in 1926. The bushel weight of the grain produced by large seed was heavier in four of the six years of the experiment, but the differences were small and not conclusive.

Large seed produced a higher percentage of large kernels than small seed in each of the five years that data were recorded. The five-year average percentage of large kernels in the large-seed plats was 35.5 as compared to 17.8% in the small-seed plats.

Hybrid kernels of natural crosses between wheat and rye, being small, were sorted automatically into the small seed in 1922 and 1923, the years following the growing of the seed plats in the vicinity of rye. In the crop of 1922 there were an average of 19 F_1 wheat-rye

hybrids in each of the seven small-seed plats as compared to 1 wheat-rye hybrid in all seven large-seed plats. Seed from unsorted Purplestraw wheat produced an average of one wheat-rye hybrid to the 40th-acre plat. In 1923, an average of six wheat-rye hybrids were present in each of the small-seed plats and two hybrids in all seven large-seed plats. Extra small seed from the threshing machine taken from unsorted Purplestraw seed wheat grown near rye produced an average of about 21 wheat-rye hybrids in each of two 40th-acre plats in 1923. The Purplestraw seed from which the extra small seed was obtained produced only two wheat-rye hybrids in 110 40th-acre plats.

Seeds of fully awned wheat rogues, which may be due to natural crossing between Purplestraw x Fulcaster, were sorted into the large seed, being themselves large, and the number present in the large-seed plats increased rapidly in each of the four years in which data were recorded. In 1924 there were 13 times as many bearded heads in the large-seed plats as in the small-seed plats, and in 1927 there were over 64 times as many. Unsorted Purplestraw seed in 1927 produced over twice as many bearded heads as small seed, but the large seed produced 29 times as many as the unsorted seed.

Three times as many loose-smutted heads occurred in the plats sown with small seed as in the plats sown with large seed in 1926 and over five times as many in 1927. Small-seed plats contained four times as many loose-smutted heads as unsorted Purplestraw seed.

SEASONAL VARIATION OF NITRATES IN WILLAMETTE VALLEY SOILS AS INFLUENCED BY LIMING AND CROPPING[1]

W. V. Halversen[2]

INTRODUCTION

The maintenance of an ample supply of nitrates for growing crops has been regarded generally as the most pressing requirement of any system of soil fertility. It is recognized, however, that nitrates may be supplied in abundance and yet crop yields may be unsatisfactory because of other limiting plant food elements or lack of moisture. Systematic studies of the nitrate content of field soils and laboratory tests on the nitrifying powers of these soils are essential in establishing the efficiency of any system of soil fertility for maintaining an ample supply of nitrates.

Each section of the country with its characteristic climatic and soil conditions presents a problem which cannot be satisfactorily solved by adopting practises and systems of management employed in other regions. An adequate supply of organic matter may be in the soil as a source of nitrates, but unfavorable soil conditions, such as moisture, temperature, or soil reaction may retard biological activity, making it too slow to supply an adequate amount of nitrates. Commercial forms of nitrogen must then be applied to meet the needs of the crop.

PURPOSE OF INVESTIGATION

The purpose of this investigation was to study the amount of nitrate produced in cropped and uncropped soils of the Willamette Valley, to determine the relation of lime to the amount of nitrates present, and to observe the seasonal variations that occur. The data herein reported were obtained from the rotation plats of the Oregon Agricultural Experiment Station at Corvallis. The soil is known as Willamette silty clay loam and is one of the most prominent soil types of the Valley. Probably 85% of it is under cultivation and the rest, mostly confined to the vicinity of streams, supports valuable forests of fir. This soil has a lime requirement of approximately 2 tons per acre and a pH value of approximately 5.4.

Management of Willamette Valley soils presents a difficult problem. More than 40 inches of rainfall annually would naturally classify the Willamette Valley as a humid region. The distribution

[1]Contribution from the Dept. of Bacteriology, Oregon Agr. Exp. Station, Corvallis, Oregon. Published with the approval of the director and the experiment station committee on soils. Received for publication May 28, 1928.

[2]Associate Bacteriologist.

of this rainfall, however, does not coincide with the growing season. The figures in Table 1 from the Corvallis Station show the mean rainfall for each month for the years 1889 to 1927, inclusive.

TABLE 1.—*Average Rainfall at Corvallis, Oregon, for the period, 1889–1927.*

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
7.09	5.66	4.24	2.63	1.97	1.18	0.32	0.46	1.72	2.98	7.10	6.61	41.96

The soils are generally heavy and acid in reaction, yet there is a diversity of opinion among investigators and laymen regarding the economic returns of lime as a soil amendment on clover, wheat, and other staple crops. Fall sowing of grains, vetches, and peas is favored because of the mild winter and the cool wet spring followed by a dry summer when moisture becomes the limiting factor. Frequently, the planting of spring crops is delayed because of excessive moisture, thus preventing maturity before the summer drought stops further growth.

HISTORICAL

One point in general agreement is that the supply of nitrates is of prime importance in plant growth, and that the factors which affect nitrate accumulation indirectly influence plant growth. Studies of the seasonal variations in the amounts of nitrate present under growing crops should show if the amount of nitrate produced is adequate to meet the needs of the crop. An examination of published reports on this subject show great variations.

Russell (6)[3] compared the nitrate content of cropped and fallow land and found that during late summer and early autumn the fallow land is the richer even after allowing for the nitrate taken up by the crop. Indeed no evidence could be obtained that any nitrate was produced in the soil during the time of active crop growth, although nitrate accumulation was taking place on adjacent fallow land. Under these conditions the nitrate content of a given soil would be a limiting factor unless adequate quantities of other forms of nitrogen were present and crops were being grown which had the power of using this nitrogen.

In contrast with the observations of Russell are the findings of Whiting and Schoonover (7) which showed an appreciable quantity of nitrate under winter wheat with different fertilizer applications all through the growing season of 1915–16. Very little loss occurred during winter. The total precipitation from December 9 to March 18 was only 9.93 inches. The nitrate content increased up to May 4,

[3]Reference by number is to "Literature Cited," p. 875.

after which time the demands of the crop materially reduced the amount of nitrate present. They found that the large use of nitrate by the wheat crop occurred during the period of May 4 to June 21, but never was the nitrate content depleted. A study of the nitrate content under oats during 1917 showed an appreciable quantity present all through the growing season.

Lyon and Bizzel (5) had previously reported differences in the nitrate content of soils under different crops. They found no nitrates in certain plats that were growing timothy for the third consecutive year, but their data seldom show complete disappearance of the nitrates.

Albrecht (1) found no significant accumulation of nitrates under grasses, including oats and timothy sod, although there was slight increase after the crops were harvested.

Wyatt, Ward, and Newton (8) found that the production of nitrates in field soils is influenced by the growing crop, the crop sequence, the method of tillage, and the moisture and temperature factors. Their data show an excess of nitrates under alfalfa, timothy, barley, wheat, corn, sweet clover, and potatoes throughout the growing season.

These few references do not constitute a complete review of the literature on this subject, but they do serve to show that regional problems do exist and must be taken into consideration in planning an adequate system of soil management.

EXPERIMENTAL

To check on the amount of nitrates present under growing crops and to establish the value of lime in aiding nitrate formation under the particular conditions of the Willamette Valley, a study was made of the rotation plats of the Oregon Experiment Station at Corvallis in which lime had failed to show marked differences in yield despite the fact that this soil has a lime requirement of approximately 2 tons per acre. The rotation is as follows: Corn (manured 10 tons per acre), fall grain, vetch, spring grain, and vetch, making a five-year rotation. Observations herein recorded were taken (a) while a crop of winter barley following corn was on the ground, (b) plats were also included that are cropped to grain continuously, and (c) four adjacent plats that had been cropped to grain continuously without fertilizer applications for nine years were limed at the rates of 0, 2, 4, and 6 tons per acre and kept fallow and heavily mulched during this experiment.

In Table 2 will be found data showing the plat fertilizer treatment, and moisture, temperature, and nitrate content of the cropped

TABLE 2.—*Percentage moisture, temperature in degrees C, and nitrate nitrogen in p.p.m. in plats cropped to barley.*

		March 20	April 4	April 18	May 9	May 23	June 15[a]	July 7	July 26	Aug. 16	Sept. 22	Oct. 19
Plat C 18	Moisture	34.7	34.5	34.5	28.6	22.1	8.6	5.0	3.7	9.4	5.4	21.2
o lime; grain	Temperature	9.4	8.0	7.0	10.2	13.7	23.5	22.8	24.0	19.2	19.5	12.2
continuous	Nitrate content	Trace	Trace	Trace	Trace	Trace	Trace	1.0	3.68	5.48	9.3	5.2
Plat D 19	Moisture	34.4	31.5	32.1	26.1	19.2	9.0	4.3	4.5	10.7	7.7	20.5
o lime; rotation	Temperature	9.5	8.7	8.5	11.1	14.0	21.0	23.7	25.0	20.5	19.5	12.2
	Nitrate content	Trace	Trace	Trace	Trace	Trace	Trace	1.4	10.5	6.40	11.9	7.75
Plat C 17	Moisture	34.5	30.7	30.8	28.0	21.9	9.0	5.5	3.0	10.4	5.8	21.2
3 tons lime	Temperature	9.1	8.7	8.5	11.0	13.2	23.5	23.5	25.2	20.2	19.5	12.5
per acre; rotation	Nitrate content	Trace	Trace	Trace	Trace	Trace	Trace	1.3	9.9	7.37	10.0	16.1
Plat C 19	Moisture	35.8	33.1	34.0	30.8	21.4	10.5	4.6	4.6	10.1	8.1	19.5
6 tons lime per acre;	Temperature	9.2	8.5	7.5	9.8	12.2	19.5	21.6	23.8	20.0	18.5	2.6
rotation	Nitrate content	Trace	Trace	Trace	Trace	Trace	Trace	1.1	3.74	7.45	13.8	4.8
Plat C 20	Moisture	35.7	32.0	33.7	30.2	23.0	9.5	3.8	3.7	9.9	6.8	22.0
9 tons lime	Temperature	9.5	8.7	7.0	10.5	13.5	25.5	23.0	23.2	20.0	18.2	13.0
per acre; rotation	Nitrate content	Trace	Trace	Trace	Trace	Trace	Trace	1.0	5.18	6.50	9.6	5.95
Plat C 22	Moisture	37.1	35.1	34.7	30.4	21.7	11.7	4.9	4.5	11.5	8.3	20.9
12 tons lime	Temperature	——	9.2	7.0	10.7	13.0	20.0	22.5	23.5	20.0	19.0	13.0
per acre; rotation	Nitrate content	Trace	Trace	Trace	Trace	Trace	Trace	1.2	6.94	4.72	11.0	5.96
Plat C 21	Moisture	35.2	31.0	34.6	27.6	20.7	7.3	5.0	5.7	10.6	8.5	24.8
o lime; grain	Temperature	9.4	8.7	7.0	10.4	12.7	21.5	22.0	22.0	19.0	18.5	12.7
continuous	Nitrate content	Trace	Trace	Trace	Trace	Trace	Trace	2.6	6.18	6.70	9.8	0.31

[a] June 15 the barley was in the thick dough stage. In four or five days the crop should be harvested.

soils. The nitrates were determined by the phenol-di-sulfonic acid method. Four samples were taken from each plat at the time of sampling.

It is quite apparent that at no time during the feeding season of the crop was there an excess of nitrates. Another factor worthy of note is that during three weeks' time (May 24 to June 15) the temperature rose to optimum while the moisture went far below optimum.

During the early growing season there seemed to be a difference in the color and vigor of the barley on the limed and unlimed plats. This contrast was not so noticeable as the barley came into maturity. At all times a marked difference could be observed in the structure of the soil. During the spring, samples of wet soil taken from the limed plats were mealy and porous, while the samples from the unlimed plats adhered to the spade and sank into the bottom of the container in a solid puddled mass. It is possible that the benefits of liming observed in the early spring were due largely to the improved physical condition of the soil.

No nitrate can be found in these limed or unlimed cropped soils during the winter and spring months, and it would seem safe to presume that the amount being produced is not adequate to meet the needs of the growing crop. It is probable that the plants which grow quite luxuriantly in the early spring while the soil is cold and saturated with water get their nitrogen in the form of ammonia. Barley is quite generally referred to as a coarse feeding crop, however, Fred (2) has shown that barley is benefited by nitrifying bacteria. The most marked crop response due to the application of lime would be expected on those plats that were growing a heavy nitrate feeding crop, such as clover or alfalfa. Since these plats are devoted to cereals and vetches such data are not available. These studies indicate the need of more nitrates during the winter and spring months to promote growth of the barley crop while moisture and temperature of the soil are not conducive to rapid nitrate formation.

NITRIFICATION AND H-ION CONCENTRATION

The nitrifying powers and H-ion concentration of these soils were determined in the laboratory. Nitrification tests were run on two different samplings by adding 100 mgs of nitrogen as ammonium sulfate to 100 grams of soil, bringing the moisture to optimum, and incubating for 28 days. The results are given in Table 3.

These results indicate a marked increase in the nitrifying power when 3 tons of lime per acre were added and a much greater nitrifying power with 6, 9, and 12 tons of lime per acre. The increases, how-

ever, are not in proportion to the amount of lime added. All the plats apparently have a vigorous nitrifying flora and a strong buffer capacity.

TABLE 3.—*Nitrification in relation to H-ion concentration.*

	Plat C 18 o lime; grain continuous	Plat D 19 O lime; rotation	Plat C 17 3 tons lime; rotation	Plat C 19 6 tons lime; rotation
May 23	44.2[a]	46.2	115.0	580.0
July 26	36.2	30.5	109.0	501.0
H-ion	pH 5.6	pH 6.0	pH 6.1	pH 7.0

	Plat C 20 9 tons lime; rotation	Plat C 22 12 tons lime; rotation	Plat C 21 o lime; grain continuous
May 23	335.5	648.0	75.0
July 26	468.0	469.0	76.7
H-ion	pH 7.2	pH 7.2	pH 6.1

[a]p.p.m. nitrate nitrogen

The H-ion concentrations were determined according to the colorimetric method suggested by Gillespie and Hurst (3). It is very evident that lime increases the nitrifying power, yet the yields of barley on these same plats fail to parallel the nitrifying powers. This may be caused by failure of the method used, but it is probable that the summer drought cut short the growing season and masked the results.

NITRATE CONTENT OF FALLOW PLATS

A series of plats that had been cropped continuously to cereals for nine years with no fertilizer treatment was limed at the rate of 0, 2, 4, and 6 tons of lime per acre. These plats were kept fallow and the moisture content was preserved with a heavy mulch. The nitrate content of the fallow plats steadily increased during the summer on both the limed and unlimed plats, 6 tons of lime per acre being responsible for the greatest nitrate accumulation. Since these plats are part of the same series reported in Table 2, it would seem safe to assume that more nitrate was being produced under the barley crop where the lime had been applied.

TABLE 4.—*Nitrogen as p.p.m. of nitrate in fallowed plats.*

	April 13	June 11	June 27	July 11	July 26	Aug. 8	Nov. 5
o lime	1.7	9.2	8.6	15.0	12.7	9.7	14.1
2 tons lime per acre	3.2	8.8	7.4	14.1	8.1	14.8	23.3
4 tons lime per acre	3.4	14.7	10.7	13.6	23.3	16.1	18.6
6 tons lime per acre	4.1	17.8	12.3	22.5	19.9	29.2	26.1

Each observation is an average of two composite samples taken simultaneously from the plat. Considering the fact that these soils were producing low yields of grain because of continuous cereal cropping with no fertilizer being added, it is quite apparent that lime does stimulate the formation of nitrates from the organic matter present in the soil.

In a previous publication the author (4) reported the results of some greenhouse studies showing the effect of lime on the yield of clover on this particular soil which is listed as Soil I. Under controlled conditions in the greenhouse the application of both 2 and 4 tons of lime per acre stimulated the growth of clover, whereas 6 tons of lime gave yields only slightly greater than no lime. This would indicate that, although lime in excessive quantities may be more effective in stimulating nitrification, this extreme condition may not be as favorable as smaller amounts on the growth of heavy nitrate assimilating plants notwithstanding that this excessive quantity of lime merely brings the pH value of the soil to 7.0.

DISCUSSION

The foregoing data bring out the fact that, although the application of lime does stimulate the production of nitrates in fallow soils and nitrification tests in the laboratory show greater nitrifying powers due to applications of lime, yet these observations alone are insufficient to predict the behavior of plants in the field.

Under Willamette Valley conditions it would appear that climatic conditions are a limiting factor. The amount of available nitrogen produced by bacterial action may well be supplemented by an early spring application of a nitrogen fertilizer to fall-sown crops to stimulate early growth. It would also appear that any system of successful cropping must take into account supplying large quantities of farm yard manure to furnish an adequate supply of available nitrogen during the long cold spring period.

CONCLUSIONS

These data portray conditions existing in the Willamette Valley of Oregon. The soil studied represents one of the most important types of the valley and is classified as Willamette silty clay loam. These studies lead to the following conclusions.

1. Low soil temperatures and excessive moisture retard nitrate formation during the winter and spring months to the extent that not more than a trace of nitrate can be found in soil under growing cereals. This humid season breaks suddenly into summer and soon lack of moisture is the limiting factor.

2. Lime stimulates nitrate production in fallow soils and also the nitrifying power of the soil as measured by its ability to produce nitrates from ammonium sulfate.

3. Climatic factors which affect soil moisture and temperature are limiting factors which mask results and make it impossible to predict crop behavior.

4. The complete disappearance of nitrates under growing cereals indicates the need of a fertilizing system which would increase the supply of nitrates during the winter and spring months.

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NOTE

EFFECT OF POTASH ON CHLOROSIS OF SOYBEANS

Soybeans on certain soils of Delaware begin to develop a chlorotic appearance shortly after the flowering stage of growth. The plants become dwarfed in appearance and the leaves curl downward at the edges and develop gray or yellowish gray areas between the veins. Usually, there is very little further growth of the plant after this condition develops.

This condition has been quite pronounced on some of the soil fertility plats at the Experiment Station, particularly where lime alone has been applied for a period of 20 years. However, there has appeared to be less chlorosis of the plants grown on the plats where fertilizers were applied, either with or without lime.

Samples of a Sassafras silt loam soil upon which the soybean plants had been badly affected with chlorosis were placed in 5-gallon earthenware jars for experiment in the greenhouse.

Commercial fertilizer materials were used as sources of materials for applications of nitrogen, phosphorus, and potassium. All treatments were made in duplicate at the rate required for a 2,000-pound application of 5–8–5 fertilizer.

In a second series of pots chemically pure salts were used to supply the fertilizer elements. A third series of pots was used to test various treatments with soluble iron and soluble manganese. Artificial illumination was required to give a length of day sufficient for normal growth.

The untreated soils produced slender plants with small, slightly chlorotic leaves. Nitrogen and phosphorus in combination produced greater growth and larger leaves but the leaves were badly affected by chlorosis. Nitrogen, phosphorus, and potassium combined applied at the time of planting produced normal growth. Nitrogen, phosphorus, and potassium combined applied after chlorosis began to develop prevented further chlorosis.

The plants on the pots receiving nitrogen alone and phosphorus alone produced greater growth than those on the untreated soils but were also more chlorotic. The plants on the soil receiving potassium alone were larger than those on the untreated soil and did not develop chlorosis.

There was no apparent difference in effect upon chlorosis between chemically pure salts and commercial fertilizer salts. The treatments with soluble iron and soluble manganese did not give any correction of the chlorosis.

These results apparently show a need of potash fertilizers for the normal growth of soybeans upon these soils.—C. R. RUNK, *Associate Agronomist, Delaware Agricultural Experiment Station, Newark, Del.*

BOOK REVIEWS

STATISTICAL METHODS FOR RESEARCH WORKERS

By R. A. Fisher. Edinburgh: Oliver and Boyd. Ed. 2. XI + 269 pp. Illus. Supplemental tables. 1928. 15/-net.

This new edition of a work that has proved of much value to the research worker concerned with statistical problems contains practically all of the material presented in the first edition with some new matter added. The author has adhered to his original plan of presenting in a practical way the application of statisticals theorems to the types of data with which the research worker is concerned without entering into a discussion of the mathematics involved.

A brief section has been added giving an abbreviated method of constructing the polynomial values fitted to a series. Also, Table VI, the table of z, has been much enlarged and is now thought to be sufficient for the great range of practical problems for which it is required.

To provide a striking and detailed illustration of the principles of statistical estimation a ninth chapter has been added on "The Principles of Statistical Estimation." This subject, in the estimation of the author, has nowhere received the practical treatment that its importance merits.

Bound at the end of the book are a series of tables which the author suggests might be removed and mounted for ready reference. These include tables of normal distribution; the table of x^2; the table of t; tables of correlation coefficients, with significant values and with transformed values; and the table of z. (J. D. L.)

PRINCIPLES OF PLANT GROWTH

By Wilfred W. Robbins. New York: John Wiley and Sons, Inc. VII + 299 pp. illus. 1927. $2.25.

This book, written in simple non-technical language, fulfills a definite need on the part of those people whose work is primarily with plants and who want to acquire a better understanding of some of the fundamental principles behind their various practices. Undoubtedly it could also be used as an elementary text in secondary schools. It should accomplish a useful purpose by bringing a modern botanical and physiological background to those whose training has been mostly practical, as well as to those who are for the first time delving into plant growth studies.

Commencing with the cell as the unit of plant structure, a comprehensive picture of the plant body as a whole is developed. Functions of the different organs are described and explained. Discussions of fundamental processes, such as respiration, photosyn-

thesis, transpiration, absorption by roots, movement of sap, etc., are given, together with mention of their inter-relation where it seems necessary. Subjects of evident practical importance, such as pruning, pollination and fertilization of flowers, seed production, seed germination and seed testing, and the propagation of plants, are all given space in this condensed and yet comprehensive and easily understandable book. A chapter is even devoted to "Weeds."

The water, temperature, light, and nutrient relations of plants are also discussed adequately. For example, under nutrient relations, plants are divided into two groups, independent and dependent, the basis for the division being whether they possess chlorophyll or not. Consideration is given to assimilation, digestion, translocation, as well as to the enzymes involved in these processes. The subject of the soil, its fertility and its bacterial content, is not forgotten, and several pages as well as a very complete diagram are devoted to the nitrogen cycle. The part played by the different mineral elements is not overlooked.

A brief explanation of the botanical classification and nomenclature of plants is likewise included, and several chapters are devoted to a discussion of the lower forms of plant life, such as the algae and the fungi. Numerous half-tones and well labelled diagrams and sketches are scattered through the book adding greatly to its value. (L. R. H.)

AGRONOMIC AFFAIRS

TWELFTH ANNUAL MEETING OF WESTERN SECTION OF SOCIETY

The twelfth annual conference of agronomists from the 11 western states met at Davis and Berkeley, California, from June 19 to 21. The attendance was good with a full program of papers and lively discussions throughout the meetings. Roll call showed the states to be represented as follows: Arizona, 1; Idaho, 1; Montana 1; Nevada, 1; Oregon, 4; Utah, 2; Washington, 8; California, 20; and U. S. Dept. of Agriculture, Washington, D. C., 3. Visiting agriculturists were present as follows: Burma, 1; India, 1 and New Zealand, 1.

PROGRAM

DAVIS, JUNE 19

I. Address of welcome, Dr. W. L. Howard, Director University Farm, Davis, Calif.

II. Response, J. W. Gilmore, President of Western Section of American Society of Agronomy, University Farm, Davis, Calif.

III. Roll Call.

IV. Secretary's report of 1927 meeting at Moro, Oregon, V. H. Florell.

V. Agronomic Problems in California, B. A. Madson, Associate Agronomist in Charge, University of California, Davis, Calif.

VI. Results of the Weed Program in Idaho, C. B. Ahlson, Field Agronomist and Seed Commissioner, Boise, Idaho.
Discussion: Dr. P. B. Kennedy, Berkeley, Calif.

VII. Soil Temperature and Paper Mulch. Alfred Smith, Associate Soil Technologist, University Farm, Davis, Calif.

VIII. What we are Doing: J. W. Gilmore, W. W. Mackie, J. P. Conrad, Dr. F. N. Briggs, J. W. Jones, C. F. Dunshee, V. H. Florell.
Visit to Agronomy Experimental Plats
4:00 P.M. Leave Davis for Berkeley.

BERKELEY, JUNE 20

IX. The Prevalence of Mixtures in Marquis Wheat grown in Central Montanta in 1926, Karl Quisenberry, Associate Agronomist, Western Wheat Investigations, U. S. D. A.
Discussion: Clyde McKee, Agronomist, Agricultural College, Bozeman, Mont.

X. Inheritance in Crosses of Marquis and Kota for Improvement in Yield and Protein Content of Montana Spring Wheat, J. A. Clark, Agronomist in Charge, Western Wheat Investigations, U. S. D. A.
Discussion: W. W. Mackie, Berkeley, Calif.

XI. Observation on the Dough Distention Method of Determining Flour Strength, D. D. Hill, Assistant Agronomist, Corvallis, Ore.
Discussion: Karl Quisenberry. U. S. D. A.

XII. The Genetics of Ridit Wheat, Karl Daniloff, Experiment Station. Pullman, Wash.

XIII. The One Variety Idea in Cotton Culture, W. B. Camp, Superintendent Experiment Station, Shafter, Calif.
Discussion: J. W. Gilmore, Davis, Calif.

XIV. Abscission of Cotton Flowers, C. P. Dutt, University Farm, Davis, Calif.

XV. The New Smut Problem in the United States, E. F. Gaines, Plant Breeder, Washington State College, Pullman, Wash.
Discussion: D. E. Stephens, Moro, Ore.

XVI. Breeding Wheats Resistant to Bunt by Backcross Method, F. N. Briggs, Junior Pathologist, U. S. D. A. Berkeley, Calif.
Discussion: E. F. Gaines, Pullman, Wash.

XVII. a. Relation between Earliness, Length of Fruiting Period, and Yield in Oats.
b. Inheritance of Color in Oats. W. W. Mackie, Associate Agronomist, Berkeley, Calif.

XVIII. Breeding for Resistance in Oats, T. R. Stanton, Agronomist, and F. A. Coffman, Associate Agronomist, Cereal Crops and Diseases, U. S. D. A. Washington, D. C.

XIX. Alfalfa Studies in California, B. A. Madson, Davis, Calif.
Discussion: George Stewart, Logan, Utah.

XX. Some Causes of Injury to Succeeding Crops from Sorghums, J. P. Conrad, Assistant Agronomist, University Farm, Davis, Calif.
Discussion: S. C. Vandecaveye, Pullman, Wash.

BERKELEY, JUNE 21

XXI. Experiment Station Teaching Applied in the Field, Leonard Hegnauer, Extension Agronomist, Pullman, Wash.

XXII. The Relation of Symbiotic and Non-Symbiotic Nitrogen Fixing Organisms to Soil Fertility, S. C. Vandecaveye, Soil Bacteriologist, Pullman, Wash.

XXIII. a. Fertilizer Requirements for Fiber Flax, W. L. Powers, Professor of Soils, Corvallis, Ore.

Discussion: J. W. Gilmore, Davis, Calif.

b. Response of Crops to Lime in Acid Soils, R. E. Stephenson, Associate in Soils, Corvallis, Ore.

c. Oxidation and Flocculation Studies with Different Sulfur Fertilizers, Joe Haynes, Experiment Station, Corvallis, Ore.

XXIV. Pasture Studies in Humid Washington, M. E. McCollam, Associate Agronomist, Puyallup, Wash.

XXV. a. Morphology of *Poa bulbosa* and Its Promise as a Forage for Ranges, P. B. Kennedy, Agrostologist, Berkeley, Calif.

b. Goat Grass (*Aegilops triuncialis*), P. B. Kennedy.

XXVI. A Comparison of Yields of Cereal Varieties Grown in Nursery Rows and Field Plats, J. F. Martin, Scientific Assistant, Experiment Station, Moro, Ore.

XXVII. Variety Tests in Cooperation with Farmers, O. E. Barbee, Assistant in Farm Crops, Pullman, Wash.

XXVIII. Some Color Reactions in a Cross Between Robust (White) and the Common Pink Bean. W. W. Mackie. Berkeley. Calif.

An invitation was extended by Dr. E. F. Gaines of Washington and C. B. Ahlson of Idaho for meeting in 1929 at Pullman, Washington, and Moscow, Idaho. A motion to accept the invitation was carried unanimously. Officers were elected as follows: Dr. E. F. Gaines, Pullman, Washington, *President;* Prof. H. W. Hulbert, Moscow, Idaho, *Secretary.*

The papers presented were of high quality and the workers are demonstrating an increasing tendency to give attention to the more fundamental aspects of their problems.—V. H. Florell, *Secretary.*

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SOIL ACIDITY METHODS AS APPLIED TO SOIL SURVEY WORK[1]

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Soil chemists are often criticized because they do not agree upon which is the best method for determining soil acidity. Much of the confusion resulting from a consideration of the large number of methods proposed for the determination of soil acidity and lime requirement has been brought about through a lack of appreciation of what is being tested for in any given method. If all these methods were measuring the same thing, just as there are several methods for determining potassium, it might still be difficult to select the best, but with the various methods dependent upon different phases of the phenomena of soil reaction, the whole situation has become highly confusing. It is with the hope of clarifying this condition that the present discussion is being taken up.

NATURE OF SOIL ACIDITY

Acid soils occur in humid climates where the rain water has leached out a relatively large proportion of the basic elements of the original soil materials. Under arid and semi-arid conditions, acidity does not develop and the soils remain neutral or basic in reaction.

Soils are acid because of a preponderance of acid silicates or of acid organic compounds. As soils vary greatly in the proportion of acid mineral and acid organic matter they contain, and as these two

[1]Report of the Subcommittee on Soil Acidity of the American Soil Survey Association. Presented at the meeting of the Association held in Chicago, Ill., Nov. 15, 1927.

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groups of acid materials are different in their action upon crops, it adds to the confusion.

Most soil investigators agree that acidity phenomena are connected largely with the colloidal fraction of the soil. There has been some controversy as to whether such acidity is due to physical or chemical reactions. The tendency now is to consider both the mineral and organic acids of soils, although colloidal, truly acidic in nature.

Michaelis (1)[3] says, "We may call a colloidal substance which has the chemical characteristics of an acid, yet produces no discrete but only colloidal ions, an *acidoid*, in distinction from a truly soluble acid."

It is generally recognized that acid soils have the capacity of absorbing bases. We have used the term "absorption" in a general way, including both chemical and physical effects, or what is meant by both physical adsorption and chemical fixation. The term "sorption" is sometimes used in this general way. Soils contain alumino silicic and humic complexes which are not only the seat of absorption phenomena, but also of ionic exchange. The bases which are held in the soil are capable of exchange with the cations of soluble electrolytes. This base exchange is reversible and quite rapid in reaching equilibrium.

Kappan (2) has classified soil acidity into three types, *viz.*, active or soluble acidity, exchange acidity, and hydrolytic acidity. In some of his work he mentions a fourth type called "neutral salt decomposition." Soils which are only slightly acid liberate an appreciable amount of titratable acidity when treated with a salt of a strong base and a weak acid, such as calcium acetate, but not when a neutral salt of a strong acid is used. This type of acidity is called "hydrolytic acidity." More strongly acid soils will liberate titratable acidity even from a neutral salt of a strong acid such as potassium nitrate. When this reaction takes place soluble aluminum appears in the solution. This is Kappan's "exchange acidity." "Neutral salt decomposition" takes place when neutral salt solutions come in contact with strong humic acid compounds and hydrogen ions appear in the solution without aluminum ions. Kappan believes that the reaction of exchange acidity is due to a direct base exchange in which the base of the salt exchanges directly with aluminum. The aluminum salt of the strong acid then undergoes hydrolysis and hydrogen ions are set free.

Hissink (5) supported by Page (3) claims that there is only one kind of acidity and it is all due to the replacement of hydrogen ions.

[3]Reference by number is to "Literature Cited," p. 890.

In the case of exchange acidity they claim that hydrogen ions are first set free then react to make aluminum soluble. Quite a number of investigators have taken sides on this question and the arguments pro and con are quite voluminous and beyond the space that can be taken for this discussion. Literature, however, contains many references to exchange, hydrolytic, and free acidity, and from the standpoint of this discussion it is important to know what the terms mean. We do not need to decide here whether there are several forms of acidity or whether all soil acidity is essentially of one kind and different only in degree.

There is one point, however, about which there should be a clear conception, and that is, what is meant by neutrality? Do we mean pH 7.07, which is exact chemical neutrality, or do we mean a point where the soil is saturated with basic elements or, in other words, all the replaceable hydrogen of the soil is exchanged for a base? The work of both Bradfield (4) and Hissink (5) indicates that colloidal clay when titrated with an alkali is not completely neutralized or saturated until a pH of between 10 and 11 is reached.

It might be thought that if we use an indicator such as phenolphthalein the faint pink end point of which is about pH 8.5 that we have thus fixed the end point in a soil acidity method. This is true for intensity of soluble acidity developed in the reaction, but it is not true for the quantity of acids. Thus, in the Hopkins (6) potassium nitrate method we measure a quantity of acidity up to about pH 6 then skip over another quantity when we go to the end point of pH 8.5. An acetate method, such as the Jones (7) method, will measure both intensity and quantity up to and just above pH 7. In other words, it should measure both exchange and hydrolytic acidity. To get hydrolytic acidity you would subtract exchange acidity from total acidity determined by an acetate method.

Methods like Tacke's (8), using calcium carbonate, and Veitch's (9), using calcium hydroxide, should measure total acidity up to neutrality and in addition include hydrogen ion replacement up to pH 8.5.

The methods determining the hydrogen ion concentration of a soil, both electrometrically and colorimetrically, measure intensity of acidity but not quantity of soil acids and have an end point of true neutrality pH 7.07.

All forms of soil acidity vary from time to time in a soil due to variations in moisture, temperature, and soil treatment, as well as to crop growth and removal.

SOIL ACIDITY AND CROP GROWTH

Different crops show a great variation in response to soil reaction. Such crops as sweet clover and alfalfa do well only on soils with slight or no acidity. Other crops, such as huckleberries, prefer a very acid soil. Many common agricultural crops seem to do best in a slightly acid soil. In acid soils the hydrogen ion has often been considered the toxic agent. Many investigators think that aluminum ions are even more toxic and there is a probability that certain organic substances are toxic. Here again the evidence indicates that crops vary as to the toxic agent by which they are most affected (10).

Just as there are toxic materials in soils, so are there also materials which counteract toxicity. Given two soils of the same pH and with different amounts of calcium, the one with the most calcium will need liming the least (11). Soils high in organic matter need lime for crop growth less than soils of the same degree of acidity but low in organic matter.

It is suggested that the toxicity of acid soils is governed by a variable equilibria in which hydrogen ions, aluminum ions, and calcium ions play a part. The presence of phosphorus, potassium, and other elements affects toxicity. Both organic and mineral colloids tend to modify the action of toxic substances in soil.

Buffer capacity of soils has been defined (12) as "that property of the soil which enables it to resist a change in its H-ion concentration by the addition of an acid or base." Calcium carbonate, silicate, or humate in the soil would be strong buffering agents against acids, while silica or humic complexes unsaturated with strong bases would be strong buffering agents against bases. Some soil acidity methods measure the buffer capacity of the silicic and humic complexes. Veitch's lime water method, for instance, is of this character.

We should keep in mind the fact that the *lime requirement of the soil* may be quite different from the amount of *lime required to grow an optimum crop.*

While a thorough laboratory investigation of an acid soil should include tests for pH, for exchange and hydrolytic acidity, and for active calcium, it is not practicable to do this in the field. For field work a determination of pH is probably the most satisfactory single test.

While it is true that all soils of like pH do not respond to lime equally, this same criticism may be made of any other soil acidity method. Likewise, the idea that acid soils need lime for the sake of calcium does not always prove true, because the addition of calcium sulfate will increase available calcium but not correct the trouble in

acid soils. Methods in which available calcium is the measure of lime requirement were long ago criticized as inadequate (19).

In general, as the hydrogen ion concentration increases, calcium decreases and soluble aluminum increases. Hence, to a certain extent, pH tests indicate the trend of the other factors. High organic matter with slight or even medium acidity indicates high calcium. A pure organic soil saturated with calcium will contain six to ten times the percentage of calcium that a saturated clay will contain.

Just as there are a large number of combinations which may constitute a good or poor hand in a game of cards, so may there be a number of combinations that may constitute a soil in need of lime or not.

The field man may, with some of the tests now available, get a good approximation of the pH of a soil. Then by observing the color estimate the organic matter. He can also tell whether a soil predominates in sand, silt, or clay. He should test the subsurface horizons and thus get additional information which will be of value in classifying soils.

METHODS

Of the numerous soil acidity methods which have been proposed, the following are representative:

A. Qualitative or roughly quantitative such as:

Litmus paper test
Soiltex
Comber's test
Truog's lead acetate paper test

B. Quantitative in that a mathematical expression is obtained.

1. Determination of intensity of acidity expressed in pH. The hydrogen and quinhydrone electrode methods as well as colorimetric methods do this.

2. Methods depending upon the treatment of the soil with a solution of a salt of a strong acid and a strong base. The Hopkins KNO_3 method is an example of this type which estimates what is known as *exchange* acidity.

3. Methods using a solution of a salt of a strong base and a weak acid, such as the Jones calcium acetate method. By subtracting the exchange acidity from acidity determined in this way, so called *hydrolytic* acidity is determined.

4. Methods depending upon the treatment of the soil with alkaline substances, such as Tacke's $CaCO_3$ or Veitch's $Ca(OH)_2$ methods.

No effort has been made to list all methods but just to select the ones more often used in this country.

QUALITATIVE TESTS

1. Litmus test.—This is probably the oldest soil acidity test in use. Distinctly acid or basic soils are easily distinguished this way. Litmus paper in contact with moist soil will respond to any soluble hydrogen or hydroxide ions, and it will doubtless be affected by any nonsoluble acidoids it may come in contact with. Faintly acid or basic soils are not easily distinguished by litmus paper. There is no way to tell how much the exchange or hydrolytic acidity affects litmus paper.

2. Soiltex.—This test (13) is a simplified colorimetric determination of pH value using bromthymol blue varying from pH 6 to 7.6. This is probably the simplest test for field work and is reasonably accurate within its limited range.

3. Comber's potassium thiocyanate test.—This test (14) is based upon the fact that a portion of the ferric iron in an acid soil is exchangeable or soluble. Soils treated with an alcoholic solution of KCNS will show a red color if the soil is acid and contains ferric iron. The depth of color depends upon two factors, the pH and the relative amount of ferric iron. To a certain extent the more acid the soil the more iron will go into solution and the deeper will be the red color, but some quite acid soils do not have enough exchangeable ferric iron to give the proper color, and waterlogged soils in which the iron is in a reduced state will not respond. Moist soils of slight acidity give less color than dry soils with this test. A relatively large amount of moist soil, however, with just enough of the reagent to show a small horizon of clear liquid above, will show pink when a smaller amount of the soil with the same quantity of reagent will show no color.

4. Truog's lead acetate paper test.—In this test (15) the soil is treated with a neutral salt of a strong acid ($BaCl_2$). The acidity developed reacts in a boiling solution upon zinc sulfid setting free hydrogen sulfid gas which in turn reacts upon lead acetate paper. The stronger the soil acidity the more H_2S is set free and the darker the lead acetate paper becomes in a given time. Under the conditions of this test, it is probable that not only soluble and exchange acidity but considerable hydrolytic acidity enter into the reaction. This test is rather cumbersome for a field test and it reacts somewhat differently with soils high and low in organic matter.

EXCHANGE ACIDITY METHODS

5. The Hopkins method.—By this test (6) the soil is treated with a neutral salt of a strong acid. Originally, NaCl was used which was

later changed by the substitution of KNO_3. The extract is titrated with an alkali using phenolphthalein as indicator. In a single treatment only a part of the acidity is made soluble, hence a factor is used to compensate. The relationship varies some for different soils. The acidity measured is largely *exchange* acidity. In soils high in organic matter some of Kappan's "neutral salt decomposition" is added to the true exchange acidity.

6. *Daikuharas method.*—Although this method (16) was published by Daikuhara about ten years later than the Hopkins method, it seems to be the exchange acidity method most used by European workers. Potassium chloride is the neutral salt used. This method has both advantages and disadvantages of the older Hopkins method. Other neutral salts of strong acids, such as nitric, hydrochloric, and sulfuric, with strong bases, such as potassium, sodium, calcium, barium, and magnesium, could be used to devise other methods for exchange acidity. They would probably give somewhat variable results, but no one would be much more valuable than the others.

HYDROLYTIC ACIDITY METHODS

7. *The Jones method.*—In this method (7) the soil is treated with a solution of a salt of a weak acid and a strong base (calcium acetate) giving a relatively high titratable acidity with a relatively low hydrogen ion concentration. At first phenolphthalein with an end point of pH 8.5 was used. Now bromthymol blue with an end point of pH 7 is often used. A factor (1.8) is applied in calculating the lime requirement. According to Kappan, this method would give hydrolytic acidity. By Hissink, this would be considered another phase of exchange acidity. It undoubtedly measures the acidity of the Hopkins method and in addition a quantity of less strong acidity. The Hopkins method often shows only a slight reaction with soils rich in organic matter, while the Jones method gives high results in such soils if at all acid. One partly acid muck tested by one of us showed a Jones acidity of 18,000 pounds lime required per million pounds soil and a Hopkins requirement of only 500 pounds. On the other hand, a subsoil clay very low in organic matter gave a Jones requirement of 4,600 pounds per million and a Hopkins requirement of 3,100 pounds per million. In the organic soil there was little exchange and much hydrolytic acidity. In the subsoil clay there was evidently relatively little hydrolytic acidity but much exchange acidity. Incidentally, the muck showed no response to liming, while the clay needed lime.

8. *The Manns test.*—Another acetate method using sodium acetate was devised by Manns (17) and has been used extensively at the Delaware Experiment Station. Other acetate methods are used in Europe (18).

METHODS USING ALKALINE REAGENTS

9. *Tacke's method.*—This (8) is one of the oldest methods for determining quantitatively the lime requirement of acid soils. An excess of $CaCO_3$ is employed and the CO_2 evolved from a reaction with the soil at room temperature is measured. The reaction in the presence of excess $CaCO_3$ takes place at a pH of about 8.5. This method is thought to measure the total lime absorption of a soil, regardless of the true neutral point. Wheeler's (19) modification of this method consists of boiling the soil and $CaCO_3$. It gives higher results than Tacke's method. The vacuum method of Ames and Schollenberger (20) is similar, except that the mixture is boiled under vacuum at about 50°C. The results obtained by this method are still higher.

10. *Hutchinson and MacLennan method.*—This method (21) employs calcium bicarbonate. The reaction goes on for three hours at room temperature. CO_2 is evolved and measured. This reaction, occurring with an excess of calcium bicarbonate, takes place at a pH of between 5 and 6. It does not give as high results as the $CaCO_3$ methods, nor even the Jones calcium acetate method. Due to the fact that calcium reacts with organic acidity more than potassium, this method gives much higher results with organic soils than does the Hopkins method. The Hutchinson and MacLennan method is used extensively in England and other European countries but not much in the United States.

11. *The MacIntire method.*—This method (22) also employs calcium bicarbonate, but the digestion is made on the steam bath and the undecomposed carbonate is determined. This reaction starts at about pH 5 and ends at pH 8.5. It gives higher results than the Hutchinson and MacLennan method. If longer time were taken, still higher results would doubtless be obtained.

12. *The Veitch method.*—Veitch's (9) method uses a strong base $Ca(OH)_2$. The soil is evaporated on the steam bath with a slight excess of $Ca(OH)_2$. The end point is the faint pink of phenolphthalein, pH 8.5. Exchangeable hydrogen ions of the soil are replaced by the basic cations. The method measures the absorptive capacity of the soil for lime under the conditions of the experiment. In other words, it measures the buffer capacity of the soil against $Ca(OH)_2$. It is a very tedious method, yet has often been employed in the United States.

13. The Bouyoucos method.—Calcium hydroxide is also used in this method (23), and the effect on the lowering of the freezing point is the measure of the reaction rather than an indicator. The shorter time and the much lower temperature are different from that used in the Veitch test, and different results are obtained.

14. Truog's $Ba(OH)_2$ method.—In this method (24) an excess of $Ba(OH)_2$ is allowed to react with the soil for one minute. Truog calls this active acidity.

15. Electrometric titration methods.—In these methods (25) determination is made of the amount of $Ca(OH)_2$ or other base necessary to bring the soil reaction to a definite pH. The soil is treated with varying quantities of lime water, and after a definite time the pH is determined. Such methods would vary, depending upon the end point selected and the time, temperature, and kind of alkali used.

pH DETERMINATIONS

16. Electrometric.—There are two such methods in common use, the older hydrogen-gas electrode (26) and the newer quinhydrone electrode (27) method. They both measure the intensity rather than the quantity of soil acidity. Schollenberger (28) has recently shown that there is a rather close correlation between the pH value and the degree of so-called "unsaturation" of the soil. An unsaturated soil would be a soil with large amounts of acidoids in the colloidal fraction. In other words, it would have replaceable hydrogen rather than basic ions.

The quinhydrone electrode (27), on account of its simplicity, is rapidly replacing the older hydrogen electrode. These methods use a soil-water suspension of 1:1 or 1:5. In Germany, KCl extracts are sometimes used but the preference seems to be for the use of water only.

17. Colorimetric pH determinations.—These were at first made with indicators of different pH end points in water extracts. This would measure intensity of soluble acidity, but such results did not check pH determinations made with the hydrogen electrode in soil suspensions. The method recently developed by Morgan (29), while essentially an approximate field method, gives more nearly concordant results with the electrometric methods, since the soil itself is present in the reacting system. With some soils there is difficulty in obtaining a clear extract to read the color.

SUMMARY

The methods for soil acidity and lime requirement determination can thus be grouped under four general heads as follows:

1. Those giving *exchange* acidity.
2. Those giving so-called *hydrolytic* acidity.
3. Those which measure *base absorption* from alkaline reagents.
4. Those which determine *intensity* of acidity by pH methods and do not determine quantity of soil acids.

VALUE OF METHODS IN SOIL SURVEY WORK

Two points of view must be considered, *viz.*, first, the study of the characteristics of the soil, and second, the practical value of the relation of the soil acidity to crop growth.

1. In a study of the composition of soils, one important phase is the reaction, especially as regards the extent of leaching and base removal. It is very evident that the various determinations give us a picture of different phases of the acidity question. If it is true that the pH value is closely related to the degree of unsaturation of the soil, then this determination should be of special value in giving a picture of the extent of leaching, or strong base removal from the soil. For a more complete picture of these relationships, both the Hopkins and Jones methods could be used. For an idea concerning the maximum absorptive capacity of the soil for strong bases some method like the vacuum method would give further information. Our modern views on base exchange have so modified our whole conception of soil acidity that no single determination will suffice to give us a complete picture of the relationships.

2. Dr. H. W. Wheeler, some years ago, raised the question, "Lime requirement for what? and for how long?" Although the results of the different methods are generally expressed in pounds of calcium carbonate required per acre of 2,000,000 pounds of soil, we know that there is no single soil acidity method which will apply to all soils and give us the optimum application of lime for different crops. This is modified by many variable factors as has been previously enumerated. Here, again, it is well to have the pH, the exchange, and the hydrolytic acidity probably important in the order named. The crop advisor will then need a large portion of experience and common sense.

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DETERMINATION OF THE QUANTITY AND "QUALITY" OF COLLOIDS IN SOILS[1]

G. W. Conrey[2]

The importance of studies of the colloidal material in soils is being stressed more and more each year. That a determination of the quantity of colloids present is desirable in connection with soil profile studies has been recognized for some time. That the quality or character of the colloid present may be of equal importance is also beginning to be recognized.

In the absence of the chairman of the subcommittee on soil colloids, the general chairman of the committee on correlative laboratory work has submitted four questions to members of the subcommittee.[3] The following discussion is based largely on answers to these questions.

1. Should methods of mechanical analysis be modified so as to include a determination of the quantity of soil colloids?

Dr. Gile states (11)[4] that a determination of colloidal material should supplant a determination of the clay fraction in mechanical analysis. It is unnecessary to determine both clay and colloid since the clay fraction includes the colloidal material.

"If one micron (0.001 mm) is taken as the upper limit for the colloidal fraction this substitution would, in the case of many soils, involve only a slight change in the statement of mechanical analysis. Results that we obtained some time ago by the ratio method of determining colloids indicated that usually about 90 per cent of the material in the clay fraction (particles below 0.005 mm) is colloidal material (particles below 1 micron). In other words, most soils apparently contain only a small quantity of material present as discrete particles of 5 microns to 1 micron in diameter.

"Although this change would not be of great moment in the case of most soils, if the clay fraction has been accurately determined, I think it is important, since it is a step toward a more accurate estimation of properties of the soil. The small quantity of material as discrete particles between 5 microns and 1 micron is similar to the true silt fraction in composition and properties, and is quite different in these respects from the bulk of the colloidal material. It should therefore form part of the silt fraction rather than of the colloidal fraction."

[1]Report for the Subcommittee on Soil Colloids of the American Soil Survey Association. Presented at the meeting of the Association held in Chicago, Ill., Nov. 15, 1927.

[2]Associate in Agronomy (Soils), Ohio Agr. Exp. Station, Wooster, Ohio, General Chairman of the Committee on Correlative Laboratory Work.

[3]The Subcommittee comprises Richard Bradfield, Missouri, *Chairman*; George Bouyoucos, Michigan; P. L. Gile, Washington, D. C.; and P. R. McMiller, Minnesota.

[4]Reference by number is to "Literature Cited," p. 898.

Dr. Bradfield (6) urges that America join with the rest of the world in the use of 0.002 mm as the upper limit of clay, because (a) the material between 0.005 and 0.001 mm resembles silt more than colloid in its properties, and (b) for the cause of international uniformity.

Gile (12) states that, since material smaller than the upper limit of clay and larger than the upper limit of colloid is present only in small quantities in most soils, the percentage of colloid should be only slightly less than that of the old clay fraction. But as a matter of fact, the colloidal material has in some instances been found to exceed the clay fraction (11).

"This is because the method of mechanical analysis that has been generally used in this country does not always give an accurate determination of the clay, owing to incomplete dispersion of the colloidal material in the case of certain soils. It is somewhat difficult to devise a routine method of deflocculation that will be satisfactory for all soils, but considerable progress in this direction has been made in the Physical Division of this Bureau and in the laboratories of Bouyoucos (5) and G. W. Robinson (17)."

Bouyoucos (4) has recently suggested that soil colloids could be defined as any soil material dried at 100° C that will give heat of wetting in water irrespective of size of particles, provided the material is completely dispersed.

"It has been found that nearly all the soil material classified as clay, and some of the very finest silt give heat of wetting. This would include soil particles as large as 0.008 mm and even larger in some soils. Above the very finest silt there is hardly any measurable heat of wetting. All the organic matter that gives heat of wetting would also be classed as colloid."

Bouyoucos has made the further suggestion (5) that

"If it is true that the colloidal portion of the soil controls almost entirely its physical as well as its physical-chemical reactions, the question arises whether, for practical purposes at least, the determination of the colloidal content of soils would be sufficient in the mechanical analysis of soils. In other words, would merely the knowledge of the colloidal content coupled with field or sight identification be sufficient in giving us a fairly true picture of a soil, at least for practical purposes."

The desirability of a determination of the colloidal material, with a possible substitution for the clay separate in mechanical analysis is emphasized by the members of the subcommittee. That the great difficulty with the method of mechanical analysis as carried out in the past has been the incomplete dispersion of the colloidal material is recognized by all.

Several valuable suggestions have recently been made for methods to secure more completely dispersion of the soil particles. That shaking with ammonia, as ordinarily carried out, does not give complete

deflocculation on many soils is recognized. Engle and Yoder (9) have used repeated rubbing with water containing a trace of ammonia. G. W. Robinson (17) emphasizes the importance of a preliminary treatment with hydrogen peroxide to decompose the organic matter. In the report (21) of a recent meeting of the First Commission of the International Society of Soil Science held at Rothamsted in 1926 it was recommended that the soil be treated first with hydrogen peroxide to decompose organic matter, and then with dilute HCl as a pre-treatment of the sample to be analyzed.

Davis (8) states that "mechanical separation of the colloid, especially from the finer grained mineral particles usually designated as silt is practically impossible by mechanical means, and the method is too laborious and time-consuming to be of service in making routine mechanical analyses of hundreds of soil samples. If dispersion of the colloidal aggregates associated with the sand groups can be accomplished, the amount of sand can be determined, the colloids estimated, and the difference will be the material between the lower sand limit (0.05 mm) and the upper limit (0.001 mm) of the colloid. The separation of the sand group by rubbing has shown that the sands can be obtained free from colloidal aggregates."

Davis recommends treatment in the usual way except that six or eight rubber balls 3/8 inch in diameter with a lead shot core are introduced in the shaker bottle and shaken with the soil. The sands, after separation by decantation from particles smaller than 0.05 mm., are rubbed with a rubber pestle before being separated by sieving.

Bouyoucos (5) has recently suggested the use of the stirring motor such as is used in mixing malted milk. Nine minutes stirring in a special cup of the soil with water containing a little KOH appears to give rather complete dispersion. If the soil is to be prepared by hand, he recommends repeated pestling of a soil-water paste.

That much more accurate results in mechanical analysis can be secured following dispersion by improved methods is self evident.

2. *What methods are best adapted for the determination of the quantity of material in the colloidal state in soils?*

It would seem that the ideal method for obtaining the quantity of colloidal material would be one such as proposed by Oden (15) in which is obtained an accumulation or distribution curve showing the quantities of the various sized soil particles as a continuous curve. Very similar methods have been used by Jennings (13), Wiegner (20), and Bradfield (7). Not only are these methods rather laborious, but the question of complete dispersion has been raised. In the light of recent studies it seems very difficult to attain, so difficult in fact as to make the results obtained by the usual methods of dispersion of questionable value. Bradfield states (6) that all of these methods are now under fire.

Bouyoucos (4) has recently stressed the importance of the activity or energy manifestations of the particles as a basis for measuring and defining soil colloids. Such energy manifestations as adsorption of water vapor, base exchange, heat of wetting, etc., are possessed only by soil colloidal material and not at all or very little by the non-colloidal material of the soil.

Based on energy manifestations, several methods have been suggested, which may be considered under the general head of ratio methods. In these methods measurement is made on the whole soil and on a sample of the isolated colloid of some property which is almost exclusively a function of the colloid. The absorption for various substances (12), heat of wetting (1, 3), base exchange (16), and binding power (14) are properties that have been used. The proportion in which the whole soil and the colloid possesses the property shows the quantity of colloid in the soil, thus

$$\frac{\text{Absorption per gram soil}}{\text{Absorption per gram colloid}} \times 100 = \%\text{ colloid in soil.}$$

The ratio methods are all more or less laborious and time consuming in that samples of the colloid must be isolated. Also, in the case of certain soils, the methods may lack in accuracy, unless a correction is applied for an alteration that seems to take place in the properties of the colloid during its isolation (1, 12).

For investigational work the undispersed colloids can be estimated microscopically by the method of Fry (10). This method has the disadvantage of being very laborious.

A fairly close approximation of the colloidal content of most soils can be obtained from a determination of water vapor absorbed over dilute sulfuric acid (about 3.3%). As most isolated colloids that have been tested by Gile and his coworkers (18) absorbed about 30% of water under these conditions, the absorption of the soil divided by 0.3 shows the quantity of colloid approximately. This method has proved useful, since many determinations can be made at one time and the manipulation is comparatively simple.

Of somewhat similar nature is the heat of wetting method. As the colloids extracted from soils show a marked difference in activity as measured by the heat of wetting, it is necessary to isolate the colloid and make such a determination on it as well as on the soil as a whole (1, 3).

Bouyoucos (5) has recently suggested the use of the hydrometer as a rapid means for estimating the colloidal material in soils. In his hands it has given results which compare very favorably with the

results obtained by the heat of wetting method. This method is admirably adapted for routine work, and should be of considerable value for comparative studies.

It is the opinion of the committee that it does not seem desirable to recommend any specific method at this time.

3. Should we go farther than a quantity measure of soil colloids?

Gile (11) states "determinations that have been made on colloids isolated from different soils show that a quality measure of soil colloids may be fully as important as a quantity measure. The colloid isolated from one soil may be four times as adsorptive and coherent, it may show several times as much heat of wetting or swelling, and it may have several times as high a ratio of silica to iron and aluminum as the colloid isolated from another soil (2, 12, 19). It thus seems obvious that the quality of the colloid should be known, if a mechanical analysis is to be used in predicting how a soil will behave or if the analysis is to be used in distinguishing different types of soil.

"Data accumulating on the chemical composition of soil colloids indicates that a single soil type and probably a group of soil types may contain very nearly the same kind of colloidal material (19). It is probable, then, that when a series of samples from the same soil type are being examined, it will be necessary to make quality determination on only a few of the samples."

4. How can the "quality"-nature or composition of the soil colloid be best determined?

Gile (11) states that "since there is a fair correlation between the degrees in which a colloid possesses such properties as heat of wetting, adsorption for gases and electrolytes, apparent size of particle, swelling and the like, and since there is a fair correlation between properties and chemical composition (2), it is necessary to determine only one or two properties in order to obtain a general idea of the quality of the colloid. Further work is needed to show just what determinations will in the long run be best adapted for giving a general characterization of the colloid. However, data that have been obtained to date indicate that it would be well to determine the molecular ratio of silica to iron and aluminum, the capacity for base exchange, and either the heat of wetting or the adsorption of water vapor over moderately strong sulphuric acid."

Bradfield suggests (6) that in addition to the single value expressions, such as heat of wetting, water adsorption, and moisture equivalent, that differences in quality are associated with differences in

1. $\frac{SiO_2}{AL_2O_3+Fe_2O_3}$ ratio.
2. $\frac{\text{Organic colloid}}{\text{Inorganic colloid}}$ ratio.
3. Nature and amount of exchangeable bases.

4. Hydration and previous history.
5. Shape and possibly size of united particles.

He says, "the precise determination to be made will depend on the particular subject under investigation. In studies of the soil profile, it would probably be well to determine the complete chemical composition of the colloid by the fusion method. In studies of the movement of water thru soils swelling and imbibed water seems to be an important determination. In studies of alkali soils the character of exchangeable bases should be determined as well as the total exchange capacity. No method has yet been proposed for determining one of the most important characteristics, namely, the state of aggregation of the colloid in the soil. This is of special importance in studying the structure of the various horizons."

SUMMARY

1. The importance of a determination of quantity of colloids in connection with mechanical analysis is stressed. The possibility of substituting such a determination for that of the clay fraction in mechanical analysis is suggested.

2. The adaptation of 0.002 mm as the upper limit for clay seems desirable as a move toward international uniformity.

3. The chief weakness of mechanical analysis as ordinarily carried out is the lack of complete dispersion. Numerous methods have been suggested recently looking toward overcoming this difficulty. The use of hydrogen peroxide in pretreatment has been especially stressed.

4. In determining the quantity of colloids the ratio methods are apparently the best available at present. The hydrometer method offers promise of being very useful.

5. The importance of the quality factor is stressed.

6. Since there is an interrelation between the various physical and chemical properties, the determination of one or two characteristics may serve to give an indication as to quality of the soil colloid. The silica-iron and aluminum ratio seems to be especially suggestive. Further study is needed to determine just what determination will serve best to characterize the quality of the colloid.

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RELATION OF CLIMATIC FACTORS TO THE AMOUNT OF NITROGEN IN SOILS[1]

HANS JENNY[2]

Numerous soil scientists in the United States and abroad agree that the distribution of the organic matter and nitrogen in the soil must be closely related to climatic conditions. This agreement, however, is not the result of specific mathematical proof. The belief that such proof is possible is the contention of the following paper. An equation for this relation has been theoretically developed and a careful study of numerous nitrogen analyses as correlated with the recorded climatic conditions of their respective localities led to its verification by these data. It proved that the total nitrogen content of the soil shows a mathematical relation to the mean annual temperature.

THEORETICAL CONSIDERATIONS

If it is assumed that the distribution of the soil's organic matter, and consequently its nitrogen, must be related to climatic conditions, it may be expressed as a general equation, thus,

$$N = f\ (\text{climate}) \tag{1}$$

where N represents the total nitrogen content of the soil and f indicates that N is some function of the climate. In other words, the soil nitrogen is in a certain way dependent upon the climate.

On analyzing the climate in relation to soil development, it is found that it consists of three main factors, *viz.*, temperature, precipitation, and evaporation. However, since it is the relation of the precipitation to the evaporation that controls the amount of water which is available to the soil, the ratio of the precipitation to evaporation may be expressed as the "humidity factor," or "moisture factor," as is often done, and then equation 1 may be put as follows:

$$N = f\ (\text{temperature, humidity factor}) \tag{2}$$

This is equivalent to saying that the nitrogen content of the soil is determined primarily by the temperature and by the humidity factor.

[1]Paper read at the meeting of the American Soil Survey Association, held in Chicago, Ill., Nov. 5, 1927. Contribution from the Department of Soils, University of Missouri, Columbia, Mo.

[2]Assistant Professor in Soils. The author is indebted to Professor M. F. Miller for encouragement and criticism, and to Professor W. A. Albrecht for carefully reading the manuscript.

Both the temperature and the humidity factor, however, are subject to great variations, hence the solution of this equation of two independent variables demands the use of the common method of keeping one variable constant while the other varies. For the one to be kept constant, let us choose the humidity factor, leaving the temperature to vary. Then, for a collection of soils, all of which have the same humidity factor, that is the same ratio of precipitation to evaporation, the following equation will apply:

$$N_H = f \text{ (temperature)} \tag{3}$$

in which the subscript H denotes that the humidity factor is kept constant or that the ratio of precipitation to evaporation does not vary. This equation simply means that in regions of similar humidity factors the nitrogen content of the soil is determined by the temperature only.[3] Just what mathematical relation there is between the nitrogen content and the temperature is not indicated by the equation, but certain well-known facts suggest it.

Nitrogen losses from the soil result from microbiological decomposition of organic matter. The biological activities are generally controlled by the rule of Van't Hoff (3, 7, 24)[4] which says that the biological activity increases two to three times for each 10° C rise in temperature, other conditions being constant. It has been found that this rule holds for lower organisms for temperatures up to 20° to 25° C (17, 21, 25). At higher temperatures the rate of change decreases and becomes zero or even negative as shown in Fig. 1. These so-called S-shaped curves are very common in biological processes. Usually they can be expressed by the formula:

$$A = \frac{a}{1 + Ce^{-kt}} \tag{4}$$

where A represents biological activity; t, temperature; and a, C, e, and k, constants.

Instead of A we may as well put CO_2 liberated, or nitrogen transformed and finally set free,[5] since these are measures of the microbiolog-

[3]By choosing the temperature as the constant in equation 2 one might derive a general equation for the variation of nitrogen in relation to different humidities, as follows: $N_t = f$ (humidity factor).

Establishing the curve for this equation becomes more difficult owing to the fact that general vegetation in the United States, and therefore the organic matter produced, varies more with the humidity factors than it does with the temperature (8). This would require the introduction of a third variable.

[4]Reference by number is to "References," p. 911.

[5]If the C:N ratio is narrow enough.

ical activity. Referring to the *nitrogen liberation from soils*, formula 4 may be written:

$$n = \frac{a}{1 + Ce^{-kt}} \qquad (5)$$

where n represents nitrogen liberated from the soil; t, temperature; a, amount of nitrogen at the beginning of the decomposition process; e, base of natural logarithm; and C and k, constants. In some cases a more elastic curve of the general type $A = a/1 + Ce^{F(t)}$ is needed, where F(t) may be represented by a Taylor series. For the sake of simplicity such curves and also lines with negative rates of change are not considered in the present investigation.

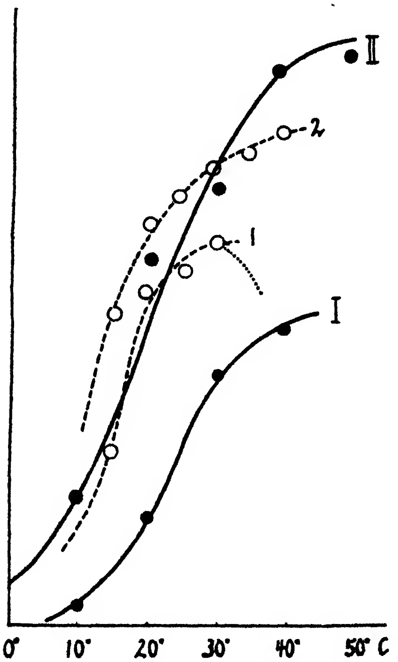

FIG. 1.—Relation between microbiological activity in soils and temperature. I and II, CO_2 evolution after Wollny (25). 1 and 2, denitrification and ammonification, respectively, after Panganiban (17).

It is obvious that a-n represents the nitrogen remaining in the soil (N) at any temperature. Solving equation 5 for a-n we obtain:

$$a - n = N_H = \frac{a}{1 + C'e^{kt}} \qquad (6)$$

in which N_H means total nitrogen content of the soil in percentage for constant humidity; t, the temperature; and a, the nitrogen content of the soil at the beginning of the decomposition process. Differentiating both equations 5 and 6, it is found after substituting $C' = \frac{1}{C} = e^{-ac}$ and $k = ak'$ that $\frac{\delta n}{\delta t} = k' n (a - n)$ and $\frac{\delta N_H}{\delta t} = -k' N_H (a - N_H)$. Since $N_H = a - n$ and $a - N_H = n$, therefore $-\frac{\delta n}{\delta t} = \frac{\delta N_H}{\delta t}$.

That is, the nitrogen content of the soil decreases at the same rate as the nitrogen liberation increases.

Equation 6 is merely the mathematical way of saying *the nitrogen content of the soil decreases exponentially when the temperature increases, provided similar humidity factors are operative.* It should be mentioned in this connection that the formula does not apply to so-called "aclimatic" soils, such as swamps, river bottoms, lake border, southern peat and muck soils, or soils on steep slopes, since their water content is not controlled by rainfall and evaporation from which the humidity factor is calculated. The equation holds, however, for humus (total organic carbon content). Numerous analyses by various experiment stations indicate a carbon-nitrogen ratio of about 10. This ratio varies with temperature, decreasing from north to south through a range from about 15 to 9.

EXPERIMENTAL EVIDENCE

In consequence of the preceding theoretical consideration the question naturally follows, Do the results of actual investigation agree with the theory and does the nitrogen content of the soil really decrease exponentially as the mean annual temperature becomes higher? For proof the following type of data are needed: (a) Analyses for total nitrogen of a great many soils, (b) the mean annual temperature of the region where each sample was taken, and (c) the humidity factor, i.e., the ratio of the annual precipitation to the annal evaporation, of the same region.[6] Within the United States these three values show a rather large variation. The percentage of nitrogen varies from 0.01 to 1.00. The mean annual temperature varies from 32° to 72°F, while the humidity factors vary from 8 to 800.

As the first step in the proof, it was necessary to group the soil samples according to their humidity factors. For this grouping two definite regions were considered, *viz.*, the semi-arid region with humidity factors ranging from 125 to 250, and the semi-humid with factors ranging from 280 to 380. The mean annual runoff (precipitation—evaporation, transpiration, deep seepage) for the former is—3 to + 5 inches, while for the latter it is 5 to 15 inches (11). Both regions run as strips about 300 miles wide from Canada to the Gulf of Mexico, a distance of 1,700 miles, or through a range in north latitude from 51° to 27° and a consequent annual temperature range for each region from 32° to about 72° F (0° to 22° C). As a second step the nitrogen

[6]It was not possible to find enough data for the precipitation-evaporation ratio (8), hence there was used the humidity factor of A. Meyer (10) in which the mean annual precipitation in mm is divided by the absolute mean annual saturation deficit of the air.

determinations for surface soils (6 to 7 inches deep) having the same mean annual surface temperature were assembled into temperature classes. The averages of the nitrogen values[7] within these classes were then plotted to their corresponding temperatures, and the constants a and k calculated. Then the theoretical values for nitrogen were calculated, and the agreement between the experimental data and the computed values noted.

SEMI-ARID REGION (HUMIDITY FACTORS 125-250)

From the semi-arid region, which includes eastern Alberta (4), southwestern Saskatchewan, (4), western North (16) and South Dakotas, eastern Montana, western and central Nebraska (15), western and central Kansas (6), the Texas Panhandle (22), Oklahoma and central and south central Texas (22), nitrogen analyses for 348 soil samples were assembled. These included all of the data available in the bulletins from the various experiment stations.

For this region the plotting of the averages of the nitrogen values against their temperatures and the calculation of the constants gives the following special equation

$$N_a = \frac{1.70}{1+e^{0.045(t-1.5)}} \tag{7}$$

in which N_a represents the total nitrogen content of the soil in percentage in the semi-arid region; t, the mean annual temperature in degrees F; and e, the base of natural logarithm. The curve of the equation as smoothed by the method of least squares, using the reciprocal mean errors as weights, is given in Fig. 2. There is a noteworthy agreement of the experimental data with the theoretical values shown in Table 1 for this region.[8] There are some deviations by the experimental values from the calculated ones, but these are small and equally distributed above and below the curve, indicating

[7]In order to make uniform the unequal distribution of the determinations in different soil types and states, the average nitrogen content of a county area was taken as the comparable unit Also, the humidity factor of every county was calculated or interpolated from surrounding values (23).

[8]The data were subjected to statistical methods. The mean error was calculated by the formula $M = \sqrt{\frac{\Sigma V^2}{n(n-1)}}$ in which M represents mean error; n, the total number of values, or county averages; and ΣV^2, the sum of the squares of the numbers formed by subtracting each value from the arithmetical mean of the whole class. The available experimental material fulfills the mathematical requirements of accuracy for this investigation.

that they are due to secondary causes only, such as (a) the variation of the humidity factor within the semi-arid region, (b) the variation of nitrogen with soil texture, (c) the differences in moisture of river bottom soils as compared with upland soils, (d) the differences between natural sod and cultivated fields, (e) the influence of natural vegetation, and others. The natural vegetation of this entire region is grass (18). The forest districts of central Texas were omitted.

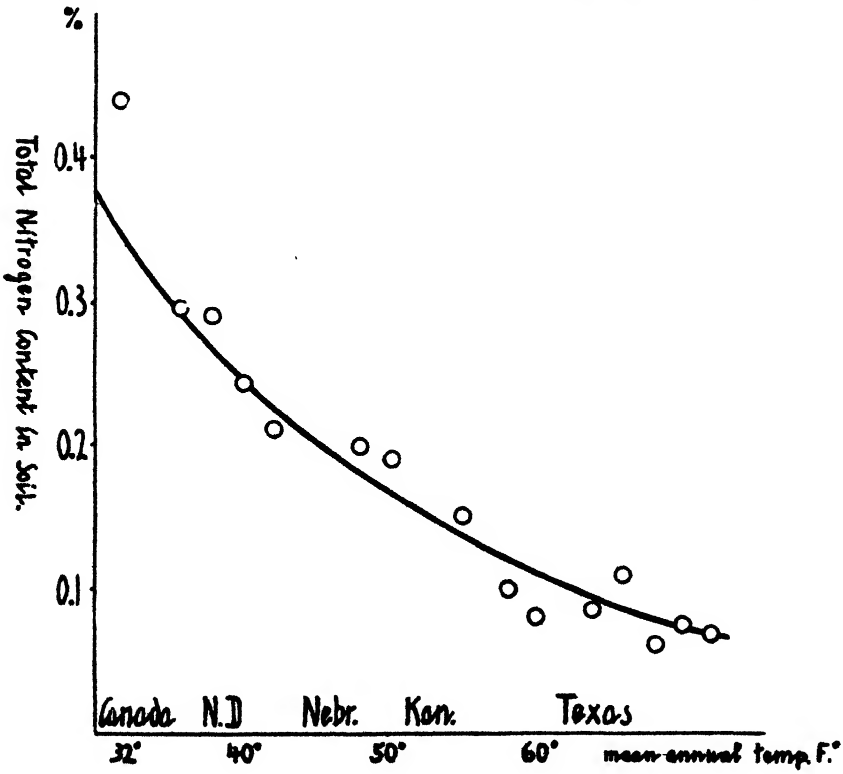

FIG. 2.—Showing average total nitrogen content of the soil as related to the mean annual temperature in the *semi-a id* region.

SEMI-HUMID REGION (HUMIDITY FACTORS 280–380)

From the semi-humid region, which includes eastern Saskatchewan (4), southwestern Manitoba, eastern North (16) and South Dakotas, southwestern Minnesota (12), Iowa (5), eastern Kansas (6), Missouri (13), Arkansas (2), and Louisiana (9), nitrogen analyses for 475 soil samples were assembled. For this region the equation has the expression

$$N = \frac{1.55}{1+e^{0.065(t-18.5)}} \qquad (8)$$

The curve is given in Fig. 3, and the agreement of the experimental data with the calculated values is shown in Table 2. The experimental data fit the theoretical curve somewhat better than in the former case on account of the greater number of analyses which gave more reliable averages. Furthermore, the abundance of data permitted one to select the analyses of only loam and silt loam soils, thus limiting the variation in texture. For sandy soils the values need to be multiplied by a value smaller than 1, and for clay soils by a value greater than 1. In addition, all river bottom soils, such as the Wabash series, for example, were omitted and only the predominating soil types of the county as shown by the soil maps were used. This procedure gave a rather small variation, and close agreement between the experimental data and the calculated values as shown in Table 2.

TABLE 1.—*Verification of the nitrogen-temperature equation in the semi-arid region.*[a]

Humidity factors 125–250.

Mean annual temperature °F	°C	State	Number of counties (units)	Number of nitrogen analyses	Average nitrogen content %	Calculated value	Deviation
32[b]	0.00	Canada	—	10	0.44[c]	0.344	+0.096
36	2.22	Canada, N. Dakota	5	30	0.295 ±0.050	0.297	—0.002
38	3.33	N. Dakota	4	5	0.291 ±0.032	0.276	+0.015
40	4.44	N. Dakota	5	12	0.244 ±0.015	0.256	—0.012
42	5.56	N. Dakota	1	1	0.21[c]	0.237	—0.027
48	8.89	Nebraska	2	17	0.199 ±0.0077	0.187	+0.012
50	10.00	Nebraska	7	28	0.192 ±0.012	0.172	+0.020
55	12.78	Kansas	6	47	0.152 ±0.022	0.140	+0.012
58	14.44	Texas	12	32	0.100 ±0.0065	0.124	—0.024
60	15.56	Texas	3	8	0.081 ±0.022	0.114	—0.033
64	17.78	Texas	3	27	0.085 ±0.012	0.096	—0.011
66	18.89	Texas	2	40	0.112 ±0.010	0.088	+0.024
68	20.00	Texas	3	25	0.063 ±0.0091	0.081	—0.018
70	21.11	Texas	13	48	0.075 ±0.0076	0.075	—0.000
72	22.22	Texas	5	18	0.075 ±0.0040	0.068	+0.007
Temperature range 40°	22.22°	Total 5	Total 71	Total 348	Range 0.44% to 0.063%	a = 1.70 c = 1.00 k = 0.045	

[a]Detailed data from which Tables 1 and 2 were summarized may be obtained from the author.

[b]Temperature estimated.

[c]Not used in calculating the constants.

The natural vegetation on the soils represented by the upper part of the curve for this region is prairie grass (18), and in order to eliminate variable vegetation only this part of the curve was used in cal-

culating the constants. The part of the curve below 56°F represents soils from southern Missouri, Arkansas, and Louisiana with original forest vegetation of mainly oaks. The experimental values from these states with forest soils are somewhat below the theoretical grassland

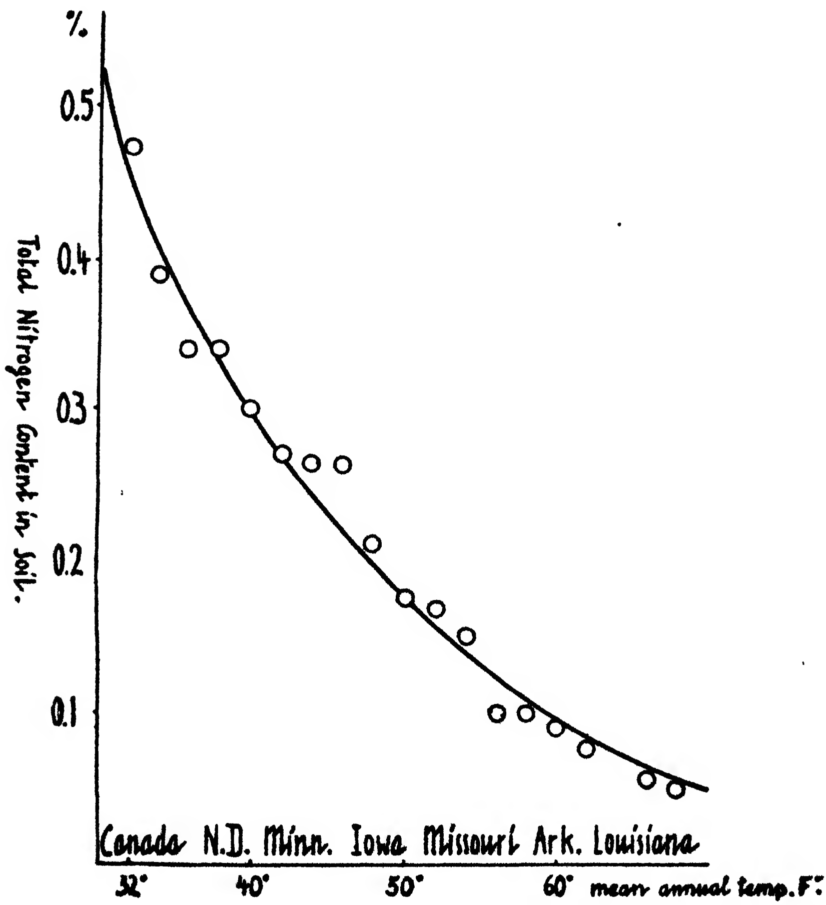

FIG. 3.—Showing average total nitrogen content of the soil as related to the mean annual temperature in the *semi-humid* region.

values, but demonstrate, nevertheless, that the exponential nature of the curve has not been changed and that within this temperature equation under constant humidity, the vegetation is of secondary influence only. (See Fig. 4.)

MEANING OF THE CONSTANTS

The constants k and a of formula 5 give an interesting insight into the nitrogen-temperature relations.

TABLE 2.—*Verification of the nitrogen-temperature equation in the semi-humid region.*

Humidity factors 280–380.

Mean annual temperature °F	°C	State	Number of counties (units)	Number of nitrogen analyses	Average nitrogen content %	Calculated value	Deviation
32[a]	0.00	Canada	—	16	*0.475*[b]	0.455	+0.020
34	1.11	Canada	1	17	*0.393*±0.023	0.414	—0.021
36	2.22	N. Dakota	7	20	*0.341*±0.017	0.376	—0.035
38	3.33	N. Dakota	4	6	*0.341*±0.083[b]	0.340	+0.001
40	4.44	N. Dakota	10	32	*0.295*±0.017	0.307	—0.012
42	5.56	Minnesota	7	17	*0.273*±0.018	0.276	+0.003
44	6.67	Minnesota	16	44	*0.266*±0.012	0.248	+0.018
46	7.78	Minnesota, Iowa	11	23	*0.266*±0.014	0.222	+0.044
48	8.89	Iowa	9	26	*0.210*±0.014	0.198	—0.012
50	10.00	Iowa, Missouri	21	54	*0.172*±0.0050	0.177	—0.005
52	11.11	Iowa, Missouri	11	60	*0.168*±0.0070	0.160	+0.008
54	12.22	Missouri, Kansas	10	56	*0.150*±0.012	0.140	+0.010
56	13.33	Missouri	13	56	*0.101*±0.0094	0.124	—0.023
58	14.44	Missouri, Arkansas	9	20	*0.098*±0.0095	0.110	—0.012
60	15.56	Arkansas	8	8	*0.091*±0.0081	0.098	—0.007
62	16.67	Arkansas	3	3	*0.078*±0.0057	0.086	—0.008
66	18.89	Louisiana	3	6	*0.056*±0.0015	0.067	—0.011
68	20.00	Louisiana	4	11	*0.050*±0.0064	0.059	—0.009
Temperature range 36°	20.00°	Total 9	Total 147	Total 475	Range 0.475% to 0.050%	a = 1.55 C = 1.00 k = 0.065	

[a]Temperature estimated.
[b]Not used in calculating the constants.

The constant k.—The constant k in equation 6 is given by the expression:

$$k = \frac{1}{t} \ln \frac{a - N_H}{C' N_H} \tag{9}$$

and is a measure of the rate of change of the decomposition velocity with respect to temperature. The k values are 0.045 for the semi-arid region and 0.065 for the semi-humid region, indicating that the temperature is more effective in the humid region than in the arid region which is in agreement with all laboratory experiments concerning microbiological activities as related to the moisture content of the soil.

Computing from Tables 1 and 2, we may state the rule that *for every 10° C fall in mean annual temperature, the average nitrogen content of the soil increases two to three times.*

The constant a.—In formula 6 the value N_H becomes equal to a when the temperature is extremely low, or in other words, when the

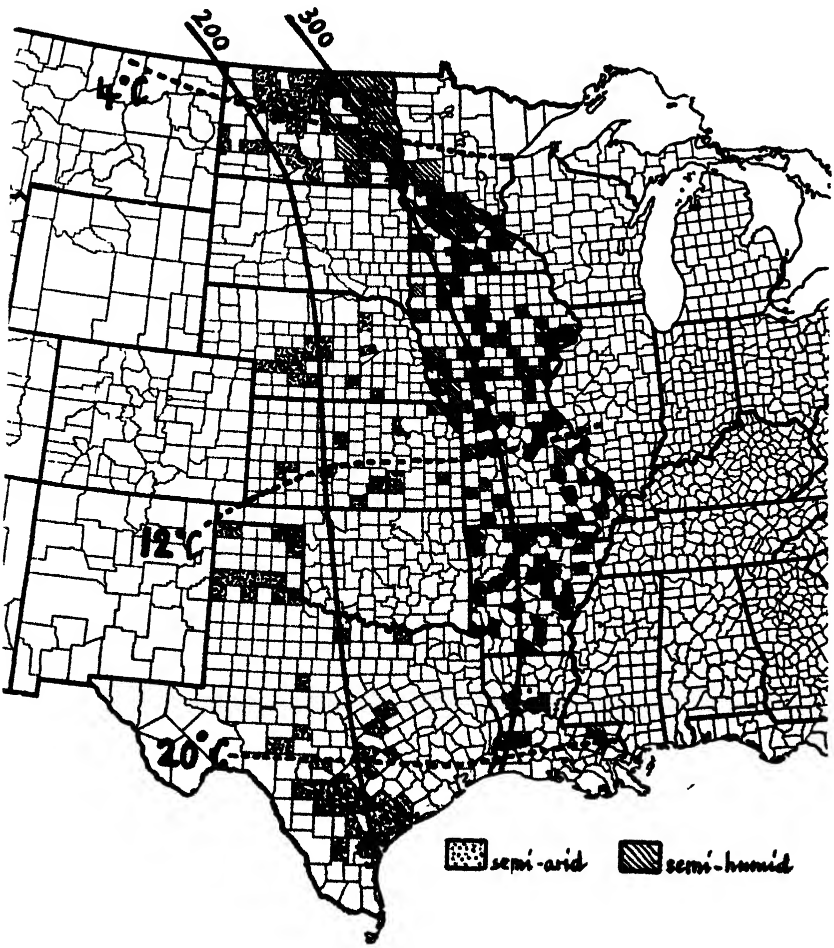

FIG. 4.- Map showing the states and counties used, the humidity lines (200 and 300), and the soil classification isotherms after Vilensky.

microbiological activity is zero and no decomposition of organic matter takes place. For the semi-humid region the nitrogen content of the soil would then be 1.55% N. As a matter of fact this value must represent the average nitrogen content of the natural vegetation, in this special case the nitrogen content of absolute dry prairie

grass. Data of Snyder show that the nitrogen content of average, semi-humid prairie hay is about 1.1% and for very good prairie hay about 1.6%. This is a remarkable agreement between chemical analyses of the vegetation and its value calculated from the nitrogen content of the soil.

DISCUSSION

This investigation has several aspects of practical importance, such as the maintenance and the increase of organic matter and nitrogen in the soil. Before the lands are plowed there is a natural equilibrium between the formation of organic matter by vegetation and its decomposition by micro-organisms, the balance between these two being determined primarily by climatic conditions. Cultivation, however, disturbs that natural equilibrium and decreases the nitrogen content of the soil, because less organic matter is returned to the soil, while the decomposition process is hastened and a loss of nitrogen results. This loss was measured by Snyder, Alway, Shutt, and others, and is about 20 to 40% of the virgin nitrogen for a cultivation period of 20 to 40 years in wheat-growing regions.

Concerning the problem of increasing the nitrogen content of the soil by green manuring and similar methods, the data of this investigation lead to the following suggestions. It seems to be possible to build up the nitrogen content of the soil by adding organic material in the *North*, because the low annual temperature would favor its preservation. The practical experiments of Snyder in Minnesota (20) and Shutt in Canada (19) tend to support this conclusion. In *southern* latitudes, however, it will be rather difficult, if not impossible, to increase permanently the nitrogen content by such practices because the high temperature militates against nitrogen accumulation by favoring decomposition. The extensive experiments of Mooers (14) in Tennessee, and also unpublished data of the Missouri Experiment Station, support this statement.

SUMMARY

1. Analysis of soil samples coming from a wide climatic range shows that the total nitrogen content of the soil decreases in the United States from north to south in relation to temperature.

2. The change of the nitrogen content with temperature is a negative exponential function, provided the rainfall-evaporation ratios are constant. For every 10° C fall in mean annual temperature, the average nitrogen content of the soil increases two to three times.

3. Practical aspects of the investigation, such as the maintenance and the increase of organic matter and nitrogen in the soil, are discussed. It seems to be possible to build up the nitrogen content of the soil by adding organic material in the North, because the low annual temperature would favor its preservation. In the South, however, it will be rather difficult if not impossible to increase permanently the nitrogen content by common green manuring practices, because the high temperature militates against nitrogen accumulation by favoring decomposition.

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THE UNAVAILABILITY OF PHOSPHORUS IN ROCK PHOSPHATE TO SOME SOUTHERN CROPS[1]

R. P. Bartholomew[2]

The small amount of total and available phosphorus in many southern soils makes the question of phosphatic fertilization very important from the standpoint of economic crop production.

Of the several kinds of phosphatic compounds sold as fertilizers, superphosphate (acid phosphate) and rock phosphate are the two which can be more readily obtained. The phosphorus can be bought much more cheaply per unit as rock phosphate, and if it is just as efficient as superphosphate (acid phosphate) in producing crops, it would materially lower the cost of production of different crops.

This investigation was started in order to study the availability of the phosphorus in rock phosphate as a source of phosphorus for some crops commonly grown in southern states.

Considerable data have been reported regarding the availability of phosphorus in rock phosphate as compared to superphosphate (acid phosphate) for a large number of crops, and several theories have been advanced to explain the variations found in the ability of plants to utilize the phosphorus in rock phosphate. Chirikov (2, 3)[3] concluded from the results of his experiments that plants having a ratio of CaO to P_2O_5 greater than 3, could make good growth upon the phosphorus in rock phosphate. Truog (8, 9) formulated a theory that the calcium oxide content of a plant was the measure of the ability of plants to utilize phosphorus in rock phosphate. Bauer (1) suggests that other factors, among which is the type of root, may determine, at least in part, the ability of plants to feed upon rock phosphate.

Of the large number of investigations made with rock phosphate, the work of Merrill (5, 6), Truog (9), and Bauer (1) give a good index to the availability of phosphorus in rock phosphate for many crops. Unfortunately, many of the important crops grown in the southern part of the United States were not included in their experiments. A summary of their results is given in Table 1.

The results on the whole agree very well, although in a few instances, such as the corn and clover crops, there are considerable differences reported in the ability of the crops to use the phosphorus in rock phosphate.

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[3]Reference by number is to "Literature Cited," p. 919.

PLAN OF THE EXPERIMENT

The plants were all grown in quartz sand in 2-gallon earthern jars with openings for drainage at the bottom. Sixteen per cent superphosphate (acid phosphate) at the rate of 500 pounds per acre and Tennessee rock phosphate at the rate of 1,000 pounds per acre were thoroughly mixed in the sand before the crops were planted. The nutrient solutions used were similar to the ones used by Truog (9). In addition 1 cc of 10% ferric chloride solution was added per jar. All legumes were inoculated with suspensions of proper bacteria after they had germinated. The plants were grown until it was evident that additional growth would not affect the results obtained. The plants were first air dried and then dried in an electric oven at 100° C for four hours.

TABLE 1.—*Availability of phosphorus in rock phosphate for plant growth as compared to superphosphate (acid phosphate).*

Crop	Relative availability		
	Merrell	Truog	Bauer
Alfalfa	fair[a]	38.3%	62.3%
Barley	poor	25.8%	——
Buckwheat	good	70.0%	72.1%
Cauliflower	good	——	——
Carrots	poor	——	——
Clover	good	6.1%	——
Clover (red)	——	——	33.3%
Clover (alsike)	——	——	50.0%
Clover (Mommouth)	——	——	50.0%
Clover (sweet)	——	——	83.0%
Corn	poor	5.6% 10.0%	41.9%
Horse beans	poor	——	——
Kohl rabi	good	——	——
Millet	——	4.1%	——
Oats	poor	9.1%	41.5%
Parsnips	poor	——	——
Peas	fair	——	——
Potatoes	poor	——	——
Rape	——	46.8%	54.1%
Ruta bagas	good	——	——
Rye	——	——	66.9%
Seredella	——	3.2%	——
Soybeans	——	——	47.7%
Red sorrel	——	——	82.9%
Red top	——	——	72.3%
Timothy	poor	——	45.2%
Tomatoes	poor	——	——
Turnips	good	——	——
Wheat	——	——	34.4%

[a]Good means almost as good as superphosphate (acid phosphate), fair is some growth, and poor is practically no growth.

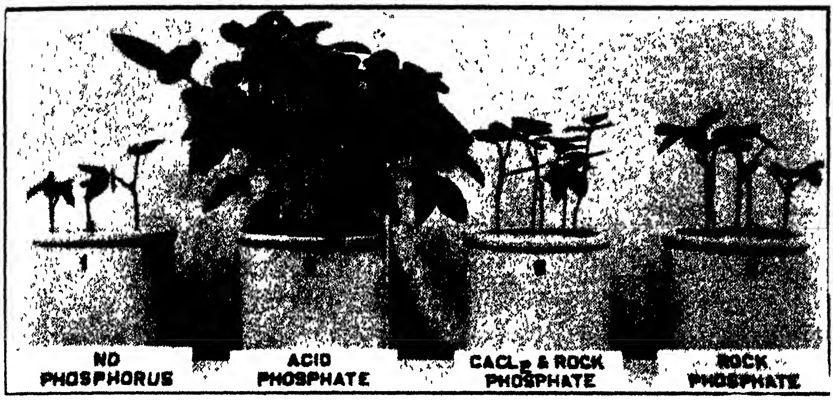

FIG. 1.—Growth of cowpeas on quartz sand with phosphate treatments indicated.

The crops used were cotton, cowpeas, vetch, sorghum, seredella, beggarweed, lespedeza, bur clover, rice, sweet clover, and velvet beans. The first crop of velvet beans was harvested after being injured by frost when the vines were about 4 feet long. A second planting was made without adding any phosphorus to the jars. The results with most of the crops were so outstanding that the jars sown to bur clover and seredella were reseeded after the first crop had been harvested. The results obtained from the second planting were similar to those of the first planting but no yields were taken as one crop had already been grown on the phosphorus supply. A second series of cowpeas were set up and grown for reasons which will be discussed later. The results obtained are found in Table 2. The growth of cowpeas and seredella as shown in Figs. 1 and 2, respectively, are characteristic of the growth of all the crops which fed very little upon rock phosphate.

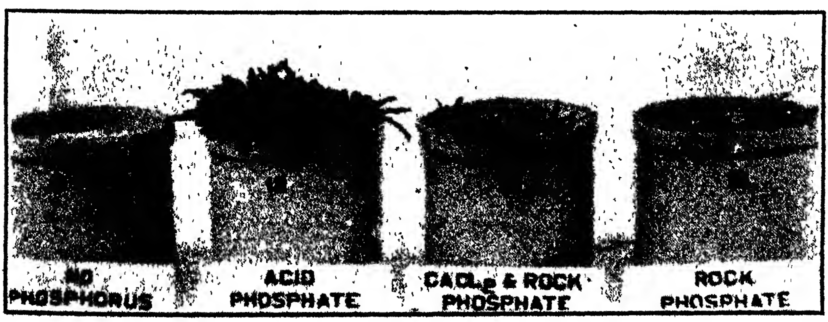

FIG. 2.—Growth of seredella on quartz sand with phosphate treatments as indicated.

It is quite evident from the results that most of the crops can not secure sufficient phosphorus from rock phosphate to make normal growth. The results with seredella and sweet clover agree very well with those of Truog and Bauer, respectively, in that seredella made practically no growth with rock phosphate and sweet clover grew almost as well with rock phosphate as it did with superphosphate (acid phosphate).

Vetch and sweet clover were the only crops to make any material growth on rock phosphate. Vetch made approximately one-third and sweet clover nearly three-fourths as much growth with rock phosphate as it did with superphosphate (acid phosphate). The other crops, *viz.*, cotton, cowpeas, sorghum, seredella, beggarweed, lespedeza, bur clover, rice, and velvet beans, made practically no utilization of the phosphorus in rock phosphate. The results demonstrate conclusively that rock phosphate has very little value as a direct phosphatic fertilizer for most southern crops. There are some factors, such as reaction of the soil and amount of organic matter in the soil, which might, under field conditions, make small amounts of the phosphorus in rock phosphate available for the plants.

TABLE 2.—*Yield of different crops with the phosphorus treatment indicated.*

Crop	Time from planting	Yield of oven-dried matter with different phosphours treatment[a]: None	Acid phosphate	Rock phosphate	Rock phosphate $+CaCl_2$
	days	*grams*	*grams*	*grams*	*grams*
Cotton	63	3.2	7.9	1.9[c]	3.1
Cowpeas	78	1.6	14.7	1.7	1.6
	63	1.9	13.2	2.4	2.4
Vetch	78	1.0	6.8	2.1	2.1
Sorghum	78	1.3	22.5	1.4	1.3
Seredella	71	0.05	7.8	0.4	0.5
Beggarweed	100	0.05	13.5	0.3	0.2
Lespedeza	63	0.1	5.1	0.3	0.2
Bur clover	59	0.05	5.8	0.2	0.2
Rice	81	1.4	22.0	1.9	1.6
Sweet clover	78	0.1	4.5	3.2	3.2
Velvet beans[b]	—	22.5	29.7	21.1	23.4

[a]Average weight of duplicate jars.
[b]Two plantings.
[c]Injured by insects.

It seems very probable that the adaption of a cover crop and green manuring program in which vetch and sweet clover are the predominating crops would at least partially solve the problem of cheap phosphatic fertilization. By this method the phosphorus taken up

from the rock phosphate would become available upon the decomposition of the organic matter. In addition the carbon dioxide liberated during the decomposition of the organic matter might help in dissolving the rock phosphate remaining in the soil.

CALCIUM AND PHOSPHORUS CONTENT OF PLANTS GROWN IN QUARTZ CULTURES

The failure of so many legume crops to make much growth on phosphorus from rock phosphate seemed rather unusual. Parker (7) states that cotton and cowpeas have a high feeding power for calcium. According to Truog (8, 9), this indicates ability to secure considerable amounts of phosphorus from rock phosphate and the crop should make fair growth. The failure of the first crop of cowpeas to feed upon rock phosphate was so marked, particularly when the above statements are considered, that a second experiment was made. The results of the second series were the same as the first.

Calcium and phosphorus analyses were made on the plant tissue from the different crops to determine if either of the theories advanced by Chirikov (2, 3) or Truog (8, 9) could account for the failure of cotton, cowpeas, sorghum, seredella, beggarweed, lespedeza, bur clover, rice, and velvet beans to use the phosphorus in rock phosphate. The results are given in Table 3.

TABLE 3.—*Phosphorus and calcium content of plants grown in quartz cultures with the phosphorus treatment indicated.*

Crop	Phosphorus treatment	P in oven-dried material %	Ca in oven-dried material %
Cotton	Superphosphate (acid phosphate)	0.324	4.59
Cowpeas, 1927	Superphosphate (acid phosphate)	0.392	1.61
Cowpeas, 1928	Superphosphate (acid phosphate)	—[a]	2.75
Vetch	Superphosphate (acid phosphate)	0.544	1.72
Vetch	Rock phosphate	0.208	2.67
Sorghum	Superphosphate (acid phosphate)	0.555	0.85
Seredella	Superphosphate (acid phosphate)	0.300	2.80
Beggarweed	Superphosphate (acid phosphate)	0.335	2.05
Lespedeza	Superphosphate (acid phosphate)	0.496	1.47
Bur clover	Superphosphate (acid phosphate)	0.394	2.50
Rice	Superphosphate (acid phosphate)	0.376	0.52
Sweet clover	Superphosphate (acid phosphate)	0.400	2.12
Sweet clover	Rock phosphate	0.313	2.77
Velvet beans	Superphosphate (acid phosphate)	0.132	2.07
Velvet beans	Rock phosphate	0.084	1.47

[a]Not determined.

A study of the results does not reveal any ratio between the phosphorus and calcium content as suggested by Chirikov (2, 3). In fact no ratio of any kind was found to exist between the phosphorus and calcium content when the crops were fertilized with superphosphate (acid phosphate). There seems to be a ratio of CaO to P_2O_5 greater than 3 where the crops where grown on rock phosphate. Unfortunately there was not sufficient plant material from most of the crops grown on rock phosphate to determine the ratio of CaO to P_2O_5 in them. The few analyses made are not sufficient to establish any ratio.

All the crops, with the exception of sorghum and rice, had a calcium content of over 1% and, according to Truog (9), should have a strong feeding power for rock phosphate. However, only vetch and sweet clover exhibited this power. The remaining crops made practically no growth on rock phosphate.

The failure of beggarweed, lespedeza, seredella, and bur clover to make good growth might be attributed to the smallness of the seeds. However, this would not account for the failure of cowpeas, cotton, and velvet beans, all large-seeded crops, to grow upon rock phosphate. While the roots were not harvested from the different crops, an examination at the time of harvest showed that in all cases the roots had grown to the bottom of the jars. Also, sweet clover, which has a small seed, made very good growth upon rock phosphate. This practically eliminates the possibility that small root development due to small seeds prevented the plants from feeding upon rock phosphate.

It would seem from the results given above as though other factors besides the calcium content of the plants controlled to a considerable extent the ability of the plant to feed upon rock phosphate. This is corroborated by results reported by Bauer (1).

Factors controlling the calcium content of a plant may be environmental, such as light and temperature, or physiological or nutritional. For example one crop of cowpeas was sown in February and harvested in May, 1927, and another set was sown in November, 1927, and harvested in February, 1928. In the first case the calcium content of the plant was 1.61% and in the latter 2.75%, or almost twice as great. The nutrient solutions used in both cases were taken from the same stock solutions. This difference may be due either to environmental or to physiological factors for the nutritional conditions were the same in both experiments.

Parker (7) reports a calcium content of cowpeas of 0.66% when grown in quartz cultures and a variation from 1.16 to 1.42% for

those grown under similar conditions in soil cultures. Henry and Morrison (4) report a calcium oxide content of 2.54% for cowpea hay. The difference in the calcium content of the cowpeas grown on quartz sand and soil cultures may have been due largely to differences in nutrients applied. In the soil cultures the differences may have been due to the other factors mentioned above.

The calcium content of cotton was much higher than would be expected under almost any conditions and yet it made practically no growth on rock phosphate.

The fact that bur clover, beggarweed, seredella, cowpeas, and cotton had a calcium content as high or higher than sweet clover or vetch when grown on superphosphate (acid phosphate) suggests very strongly that other factors than the calcium content of plants may control to a considerable extent the ability of plants to utilize the phosphorus in rock phosphate.

SUMMARY

Eleven crops commonly found in southern states were grown in quartz cultures with different phosphorus treatments in order to determine their ability to use rock phosphate as a source of phosphorus for plant growth.

Analyses were made on the plant tissue for calcium and phosphorus to see if they had relation to the feeding power of plants for rock phosphate. The results may be summarized as follows:

1. Cotton, cowpeas, sorghum, seredella, beggarweed, lespedeza, bur clover, rice, and velvet beans made very little growth when phosphorus was supplied as rock phosphate. Vetch made about one-third and sweet clover about three-fourths as much growth from rock phosphate as with superphosphate (acid phosphate).

2. There was no definite relation between the calcium-phosphorus ratio in the plants and their ability to feed upon rock phosphate.

3. Other factors than the calcium content of the plants seem to play an important part in determining the ability of plants to use rock phosphate as a source of phosphorus.

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THE RELATION OF EXCHANGEABLE CATIONS TO THE PHYSICAL PROPERTIES OF SOILS[1]

L. D. BAVER[2]

The physical properties of soils are in part dependent upon the size and arrangement of the soil particles. A sandy soil, with its relatively coarse particles, has certain well-defined physical characteristics that are quite different from those occurring in a clay soil which contains a high percentage of fine particles. The pronounced difference in the physical properties of these two classes of soil is undoubtedly the result of differences in the amount and nature of the colloidal material present.

Recent investigations in the field of soil colloids have shown that the physical properties of soils are controlled almost entirely by the colloidal material present (23).[3] Some workers have gone so far as to say that all physical properties and activities of soils are dependent entirely on the soil colloids. If we consider the complex physical composition of the soil, we can conceive that the physical phenomena observed in soils, such as water-holding capacity, absorption of water, heat of wetting, flocculation and deflocculation, plasticity, etc., may be the result not only of the amount of colloidal matter but also of the nature of the colloids. The colloidal material may be present as discrete particles or as coatings around the larger soil grains. The physical phenomena are perhaps dependent upon the state in which these colloids exist. They may be present in the gel or sol form. The nature of their respective surfaces, upon which their relative chemical and physical activity depends, may be different (6).

If the nature of the soil colloidal matter plays an important part in the physical properties of soils, we should expect differences in the activity or behavior of soil colloids as a result of the specific cations that may be found on the absorbing complex. Hissink (13) states that, "there is an undeniable relationship between the structure of the soil and the relative proportion of the adsorbed bases. As Na comes into evidence, soil structure deteriorates." Gedroiz (10, 17) reports that, "the degree of colloidality of any soil depends on the state of saturation of the soil and on the nature of the exchangeable bases." Sokolovski and Lukaschewitsch (24) assert

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[3]Reference by number is to "Literature Cited," p. 940.

that the absorbed cations have a different effect on the physical properties of the soils that absorb them. Hager (12) reports that Na and K salts hardened "argillaceous soil" and spoiled its workability, aeration, water percolation, and water capacity. Soil overflowed with sea water had a poor structure for a year when the sea water was displaced by rain water. Liming, on the other hand, improved the workability of the soil. He says that, "all these structure changes result, along with many others, through changes in the condition of the soil colloids." Sharp (22) comments that the, "substitution of Na for Ca, Mg and other bases in the silicate complex or the direct addition of Na to such a complex results in the formation of new jelly-like colloids, capable of becoming highly dispersed when in contact with water." Kelly and Brown (14) report that soils saturated with Na are sticky when wet and harsh when dry. Ca salts, on the other hand, produce a relatively porous soil. Thus, it appears that the physical properties of soils are in part dependent upon the nature of the cations on the absorbing complex.

It is the purpose of this paper to report a study of the relation of the exchangeable cations Ca, H, K, Mg, Mn, and Na on the absorbing complex of soils (soil colloidal material, organic and inorganic) to the physical properties of soils as measured by the following determinations: (a) Moisture equivalent, (b) hygroscopic coefficient, (c) heat of wetting, (d) state of flocculation or deflocculation, (e) rate of slaking, and (f) Atterberg plasticity constants.

EXPERIMENTAL

Five soils of widely different nature were selected for this study, as follows:

1. Toledo silty clay. 0–5 inches. Gray-black silty clay. Reaction: pH 6.44. Absorptive capacity: 31.85 mgm. equiv. NH_4 per 100 grams of soil. Degree of saturation: 95%.
2. Toledo silty clay. 14–18 inches. Mottled bluish-gray and yellowish-brown clay, approaching a silty clay. Reaction: pH 7.34.
3. Ellsworth silt loam. 17–28 inches. Mottled brownish-drab and yellowish-brown heavy clay. Reaction: pH 4.45. Absorptive capacity: 14.27 mgm. equiv. NH_4 per 100 grams of soil. Degree of saturation: 53.6%.
4. Ellsworth silt loam. 28–40 inches. Olive-yellow brittle clay. Reaction: pH 5.30. Absorptive capacity: 13.11 mgm. equiv. NH_4 per 100 grams of soil. Degree of saturation: 76.7%.
5. Clermont silt loam. 0–8 inches. Gray silt loam. Reaction: pH 4.90. Absorptive capacity: 9.19 mgm. equiv. NH_4 per 100 grams of soil. Degree of saturation: 68.5%.

TABLE 1.—*Mechanical analyses of soils used.*

Soil	Depth in inches	Fine gravel %	Coarse sand %	Medium sand %	Fine sand %	Very fine sand %	Total sands %	Silt %	Clay %
Toledo silty clay	0–5	0.1	0.25	0.55	2.40	9.30	12.60	48.70	40.60
Toledo silty clay	14–18	0.15	0.25	0.75	3.35	8.75	13.25	44.85	44.70
Ellsworth silt loam	17–28	0.80	0.55	1.00	2.80	9.10	14.25	44.80	40.70
Ellsworth silt loam	28–40	0.90	0.65	1.10	2.65	11.60	16.90	45.70	37.20
Clermont silt loam	0–8	0.65	1.55	3.80	7.95	13.50	27.45	54.40	20.70

TABLE 2.—*Exchangeable base content of soils used.*[a]

Soil	Depth in inches	Exchangeable bases, mgm. equiv.							NH_4 absorbed mgm. equiv.	Degree of saturation %
		Ca	Mg	Mn	K	Na	H	Total		
Toledo silty clay	0–5	22.97	6.29	0.008	0.10	0.90	3.38	33.65	31.85	95.0
Ellsworth silt loam	17–28	3.71	3.41	0.002	0.23	0.30	6.82	14.47	14.27	53.6
Ellsworth silt loam	28–40	5.59	4.01	0.004	0.16	0.32	2.80	12.88	13.11	76.7
Clermont silt loam	0–8	4.11	1.43	0.062	0.12	0.58	3.04	9.34	9.19	68.5

[a]Analyses by F. R. Dreibelbis.

Mechanical analyses and exchangeable base content of these soils are given in Tables 1 and 2, respectively. Exchangeable bases were not determined on Toledo silty clay, 14 18 inches, because of an insufficient quantity of sample.

TABLE 3.—*Reaction of soil, leaching solution, and leachate.*

	Treatment[a]	Soil pH	Solution pH	Leachate pH	cc N/10 NaOH per 50 cc leachate
Toledo silty clay	None	6 44	—	—	—
	Ca	7.65	7.46	6.38	—
0–5 inches	H	3 55	1.25	2.25	6.9
	K	7 90	6.50	6.30	—
	Mg	7.53	6.90	6.35	—
	Mn	6 55	7 10	6.35	—
	Na	8 15	7.80	6.50	—
Toledo silty clay	None	7 34	—	—	—
	Ca	7.70	7.46	6 75	—
14–18 inches	H	4.00	1.25	1.75	15.0
	K	7.94	6.50	6.45	—
	Mg	7.50	6.90	7.00	—
	Mn	6.55	7.10	6.60	—
	Na	8 22	7.80	7.00	—
Ellsworth silt loam	None	4.45	—	—	—
	Ca	7.00	7.00	6.00	9.5
17–28 inches	H	3.11	1.25	1.80	33.5
	K	7.72	7.00	6.30	9.0
	Mg	7.05	7.00	5 85	10.0
	Mn	6.16	7.00	5.80	10.0
	Na	6.80	7.00	6.10	12.0
Ellsworth silt loam	None	5.30	—	—	—
	Ca	7.47	7.00	6.00	6.0
28–40 inches	H	3.22	1.25	1.80	28.5
	K	7.90	7.00	6.60	4.5
	Mg	6.75	7.00	6.20	4.0
	Mn	6.70	7.00	6.10	5.5
	Na	7.15	7.00	6.40	5.0
Clermont silt loam	None	4.90	—	—	—
	Ca	7.50	7.00	5.85	7.5
0–8 inches	H	3.30	1.25	1.30	34.0
	K	8.10	7.00	6.50	6.5
	Mg	7.60	7.00	6.30	4.0
	Mn	7.05	7.00	6.15	6.5
	Na	8.05	7.00	6.25	6.0

[a]Normal acetate solutions of these cations were used to leach the soil, with the exception of H where N/10 HCl was used.

With each of these soils 600 grams were saturated with Ca, K, Mg, Mn, and Na by leaching with 2,000 cc of normal acetate solutions of the respective cations. The soil was saturated with H by leaching with N/10 HCl. The reaction of the normal acetate solutions, made from the different acetate salts, was not adjusted in the case of the Toledo silty clay. Their reaction ranged from pH 6.50 to pH 7.80. The reaction of the solutions, with the Ellsworth and Clermont silt loam, was adjusted to pH 7.00, either by the addition of acetic acid or the corresponding base. Table 3 shows the reaction of the soil, the leaching solutions, and the leachate, together with the cc of N/10 NaOH required to neutralize the acidity of 50 cc of the leachate.

The excess salts were removed by leaching with 2,000 cc of distilled water. In the case of the K- and Na-saturated soils, 2,000 cc of 80% alcohol were used in the washing process. Distilled water caused a puddled condition which made the soil mass impervious, thereby making washing impossible.

The rate of percolation of the acetate solutions was approximately the same for each soil. However, when the excess salts were being removed, the soil became compacted and permeability was decreased, with the exception of the soil saturated with the Ca ion. This decrease in permeability was greatest with the Na and K ions. The Ca ion increased the permeability to some extent.

Nollte and Sander (16) report that solutions of neutral salts of the higher alkali metals at first increased the permeability of soils washed with water. A compaction occurred when the salts were being washed out. The Ca ion was "decisive, in general, for the structure and permeability of natural soils." Nollte (15) claims that in the washing process the salts that produce crumb structure are washed out and the permeability of the soil is decreased. He observed that ions showing a strong hydrolysis produced the strongest compaction and that the Ca ion increased the permeability. Sharp (22) states that the water removes from the sphere of action any flocculating agents that may be present in the form of soluble salts.

During the washing of the soils saturated with Na, K, and Mn, a dark-colored, rather fluffy, colloidal-like material was observed in the filtrate. This effect was especially noticeable with the surface soils and was probably due to the organic matter.

The leached soils were air-dried, crushed to pass a 2-mm sieve, and the above-mentioned physical determinations carried out.

EFFECT OF EXCHANGE CATIONS ON PHYSICAL PROPERTIES OF SOILS

MOISTURE EQUIVALENT

The moisture equivalent affords a means of comparing soils on the basis of their capacity to hold water against a definite and constant centrifugal force 1,000 times the force of gravity. It represents the capillary capacity of a soil of minimum column length under a known constant force. The finer the soil, the greater is the moisture equivalent. It has been correlated with the textural properties of soils, water-holding capacity, wilting coefficient, etc.

The data in Table 4, Column 1, show that, with the exception of the Na ion, the different cations have produced no significant effect on the moisture equivalent of these soils. However, there has been a tremendous increase with the soils saturated with Na, ranging from 28% in the Clermont silt loam to 193% in the 14-18 inch horizon of the Toledo silty clay. In every case, the soil was so puddled and impervious to water that the soil in the moisture equivalent cups was covered with water after centrifuging 40 minutes at 2,440 revolutions per minute. The water was squeezed out rather than passing through the soil. This phenomenon has been observed in alkali soils and is due to the high dispersive action of the Na ion.

HYGROSCOPIC COEFFICIENT

The hygroscopic coefficient is a method for comparing soils based on the ability of the soil to absorb water from a saturated atmosphere at a constant temperature. The amount of water that a soil will absorb depends on its colloidal content. This absorption depends on the size of the particles, which is directly associated with the amount of surface area, and the nature of the particles, i.e., their state of decomposition and the nature of their surfaces.

Robinson (19) has found that the average value of the absorption of water vapor (over 2% H_2SO_4) by ultra-clays is about 0.298 gram per gram of colloid, regardless of the source of the colloid. In other words, all colloids absorb about the same amount of water under these conditions. It is possible, therefore, to estimate the amount of colloids in a soil by determining the hygroscopic coefficient and dividing it by the above factor.

The results in Table 4, Column 5, and illustrated in Fig. 1, Column 3, indicate that, with the exception of the K ion, the different cations have not materially affected the hygroscopic coefficient (2% H_2SO_4). In other words, the replacement of the cations originally occurring on the absorbing complex of the soil colloidal material by one specific

ion has produced no significant changes which would indicate that more colloidal matter has been formed in the exchange process. The K ion, on the other hand, has lowered the amount of water absorbed. This decrease in the hygroscopic coefficient value probably does not mean that there has been a reduction in the amount of colloidal matter present but is due perhaps to the lower absorptive power of the colloids in the soil.

If the absorption of water is carried out in a drier atmosphere (30% H_2SO_4), the colloidal material will absorb water vapor in amounts specific for each colloid, i.e., different colloids will absorb

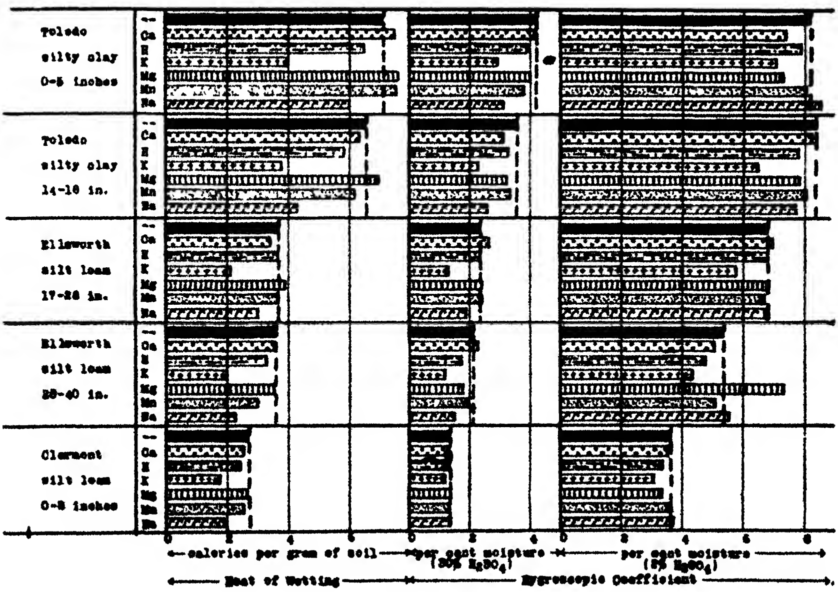

FIG. 1.

different amounts of water. The results in Table 4, Column 6, and Fig. 1, Column 2, show that the K and Na ions have caused a decrease in the amount of water absorbed. The other cations have produced no significant changes in the hygroscopic coefficient under these conditions (30% H_2SO_4).

From a comparison of the results obtained in the hygroscopic coefficient of these soils, determined over 2% and 30% H_2SO_4, it is seen that the monovalent ions, K and Na, have caused a change in the nature of the colloidal material. These two ions have reduced the absorptive power of the soil for water vapor, which is reflected in a lower hygroscopic coefficient value. The effect of the K ion is

TABLE 4.—*Physical determinations of variously treated soils.*

Soil	Treatment	Moisture equivalent % moisture	Plasticity range, % moisture: Lower limit	Plasticity range, % moisture: Upper limit	Plasticity number	Hygroscopic coefficient, % moisture: 2% H_2SO_4	Hygroscopic coefficient, % moisture: 30% H_2SO_4	Heat of wetting cal gr soil	State of floccula-tion[a]	Rate of slaking Hrs. Min.
Toledo silty clay ...	None	32.55	34.60	42.17	7.57	8.25	4.15	7.05	*****	1—15
	Ca	34.44	32.19	42.21	10.02	7.45	4.14	7.53	******	1—15
	H	32.68	32.99	40.06	7.07	7.94	3.91	6.50	****	0—30
	K	——	32.25	39.46	7.21	7.14	2.91	3.98	*	——
0–5 inches	Mg	35.47	33.49	43.28	9.79	7.35	4.00	7.61	***	1—15
	Mn	34.45	32.83	43.89	11.16	8.09	3.76	7.55	*******	1—15
	Na	60.98	27.60	41.50	13.90	8.63	3.08	5.99	—	5—30
Toledo silty clay.....	None	28.90	28.92	42.13	13.21	8.40	3.50	6.51	******	1—00
	Ca	28.65	26.61	41.92	15.31	8.28	3.15	6.34	*******	0—45
	H	28.72	28.07	39.90	11.83	7.86	3.30	5.86	***	0—15
	K	——	29.20	38.60	9.40	6.52	2.30	3.74	*	——
14–18 inches	Mg	30.22	25.39	41.79	16.40	7.92	3.49	6.99	*****	1—30
	Mn	31.46	27.07	42.00	14.93	8.13	3.61	6.18	********	2—15
	Na	84.80	23.86	38.98	15.12	7.75	2.67	4.31	—	10—00

Ellsworth silt loam...	None	26.80	22.90	29.50	6.60	6.77	2.34	3.67	*******	0—20
	Ca	25.77	22.30	29.56	7.26	7.00	2.64	3.40	****	0—30
	H	26.85	25.00	32.56	7.56	6.85	2.36	3.63	******	0—10
	K	26.25	22.14	27.60	5.46	5.80	1.30	2.08	*	1—00
17–28 inches	Mg	26.25	22.25	30.46	8.21	6.81	2.40	3.88	*****	0—25
	Mn	27.60	22.62	31.60	8.98	6.70	2.43	3.68	********	0—25
	Na	37.50	19.85	28.80	8.95	6.77	1.88	2.96	—	4—00
Ellsworth silt loam..	None	25.07	21.37	26.95	5.58	5.32	2.03	3.56	******	0—20
	Ca	25.78	20.69	26.61	5.92	5.05	2.27	3.53	**	0—20
	H	25.87	24.72	32.32	7.60	4.80	1.76	3.28	****	0—15
	K	25.50	18.92	22.85	3.93	4.34	1.20	2.00	*	1—15
28–40 inches	Mg	25.61	19.85	26.33	6.48	7.32	1.77	3.53	********	0—45
	Mn	26.18	21.56	26.50	4.94	5.06	1.97	2.96	*******	0—20
	Na	33.70	18.50	23.54	5.04	5.56	1.50	2.25	—	4—00
Clermont silt loam...	None	24.02	21.40	23.43	2.03	3.61	1.32	2.64	********	0—06
	Ca	24.07	20.60	23.78	3.18	3.55	1.35	2.56	***	0—11
	H	23.79	20.40	23.38	2.98	3.34	1.32	2.44	****	0—07
	K	24.88	17.35	19.40	2.05	3.05	1.19	1.76	*	1—30
0–8 inches	Mg	24.45	20.04	23.40	3.36	3.33	1.38	2.64	**	0—15
	Mn	24.80	20.23	23.71	3.48	3.68	1.42	2.56	***	0—08
	Na	33.42	16.76	20.22	3.46	3.69	1.36	1.92	—	7—00

[a]The degree of floculation is shown by the number of asterisks, the maximum being designated with eight asterisks. A minus sign indicates extreme deflocculation.

different from that of Na with the 2% H_2SO_4. If we consider that the absorptive power of the colloid has been reduced by these ions, then there has been no reduction in the amount of colloidal material with the K ion, as might be inferred by the results. On the other hand, the Na ion probably has increased the colloidal content, since in the one method (30% H_2SO_4) there has been a reduction in the absorptive capacity of the colloid with no significant change in the absorptive power of the soil, according to the other (2% H_2SO_4).

Sharp (22) reports that the hygroscopic coefficient and dye absorption showed no increase in the amount of colloidal material in a salt-treated soil. There was no increase in the amount of interior surface exposed. However, he states that Na and K salts form new colloidal substances. It is evident from the results shown in Fig. 1 that there has been a decided change in the colloidal matter with these two ions, either in the amount of colloids in the soil or in their nature or both.

HEAT OF WETTING

The heat of wetting is based on the heat evolved when a soil is thoroughly wetted with water This phenomenon is directly dependent upon the soil colloidal material and is specific for different colloids. It is used as an indirect method for determining the amount of colloids in the soil by dividing the heat of wetting of the soil by that of the extracted colloid (1).

The effect of exchange cations on the heat of wetting of these soils is shown in Table 4, Column 7, and Fig. 1, Column 1. The monovalent K and Na ions have decreased the heat of wetting. The K ion has produced the greatest diminishing effect Pate (18) also found that soils saturated with monovalent ions generally have a low heat of wetting. The divalent cations and the H ion have produced insignificant effects.

It is interesting to note the correlation between the hygroscopic coefficient as determined over 30% H_2SO_4 and the heat of wetting. These methods are based on the specific properties of the different colloids and in both cases there has been a reduction in the activity of the colloidal material in the soils saturated with K and Na, the K ion exerting the greater diminishing influence.

STATE OF FLOCCULATION

By the flocculation of soil particles in a soil suspension is meant the grouping of the particles into small aggregates, or floccules, with a subsequent settling out from the dispersion medium. Deflocculation of soils is that state in which the individual particles are separately

suspended in the medium. In the latter case, only the larger particles settle out, the finer ones remaining in suspension almost indefinitely depending upon the thoroughness of deflocculation.

A soil in which the finer particles are in a flocculated condition has a relatively granular or porous structure which is reflected in better aeration, workability, etc. On the contrary, if the finer particles are deflocculated there is a tendency towards puddling, a more compact structure, poorer aeration, workability, etc.

Comber (8), in studying the flocculation of soils, found that the Ca ion had a specific flocculating action on clay soils having an alkaline reaction. Alkalinity decreased the flocculating effect on silt. Bradfield (4) reports that the Ca ion is ten times as efficient as a flocculating agent as the K ion Gedroiz (11, 17) states that dispersion is increased by the H ion when compared with the di- and tri-valent ions and decreased when compared with the monovalent. Hissink (13) says that there "is some relation between the quantity of lime required for flocculation of the watery clay suspensions and the degree of saturation of the clay substance, the lower the degree of saturation the more lime is required for flocculation" De Sigmond (9) reports that in heavy clay soils, lime converts the very fine dispersion of clay into a coarser dispersion Wolkoff (25) shows that the salts of heavy metals are more flocculent than those of the lighter ones.

In this study of the relation of different cations to the state of flocculation, two different methods were used. The soil was thoroughly dispersed for five minutes in a drink-mixing machine, the soil-water ratio being 1:5. The suspension was transferred to a graduated cylinder and changes in the specific gravity with time were observed by using an hydrometer. After 24 hours, the suspension was thoroughly shaken, transferred to a long settling tube, and pictures of the different suspensions taken at 2-hour and 24-hour intervals. In this way two checks on the state of flocculation were obtained. The results of these flocculation experiments are discussed below.

1. Toledo silty clay, 0 5 inches, pH 6.44.—The state of flocculation of these soil suspensions is shown in Fig. 2. If these suspensions are arranged in order of decreasing flocculation, the following order is obtained: Mn, Ca, original soil, H, Mg, K, and Na. The Mn-saturated soil was flocculated to such an extent that a curdy flocculate was formed which was so concentrated that hydrometer readings could not be made. In other words, the suspension settled in a continuous column. The curdy flocculate did not settle out as distinct floccules, but there appeared to be an entrainment of all the particles. This phenomenon occurred to a less extent, after 5 hours, in the original

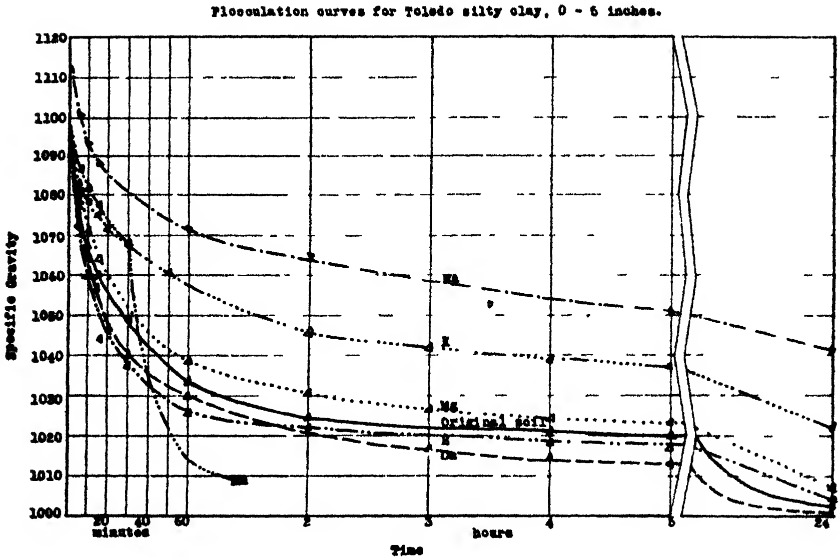

FIG. 2.

soil and the one saturated with the Ca ion. The H ion caused a flocculation of the larger particles, but not of the finer The soils saturated with K and Na were in a deflocculated condition

2. *Toledo silty clay, 14 18 inches, pH 7.34.*—The results of this experiment are given in Fig. 3. Flocculation took place in the order

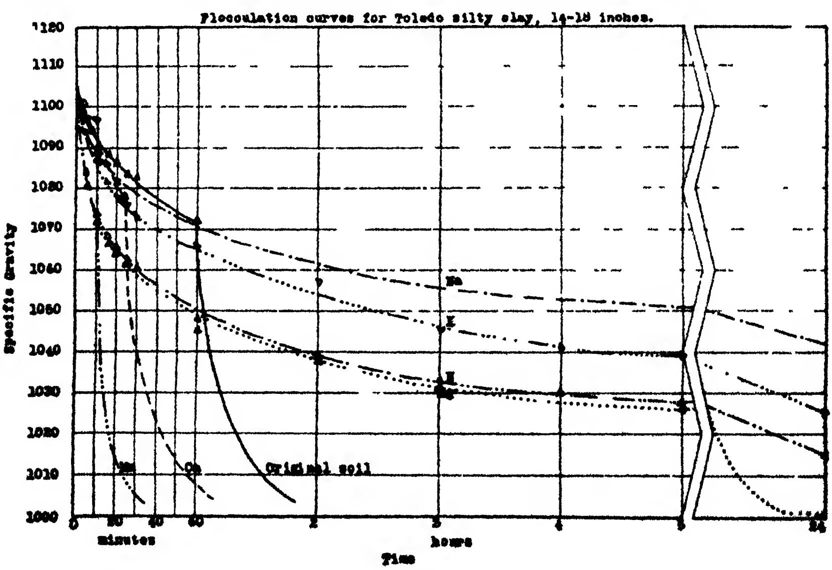

FIG. 3.

of Mn, Ca, original soil, Mg, H, K, and Na. The distinct flocculating effect of the Mn ion is also evident in this soil. The flocculate was of a curdy nature in all of the flocculated suspensions. The K and Na ions have produced deflocculating effects. The larger particles appear to be flocculated in the H-saturated soil. The strong flocculating action of the Ca ion is well marked in this soil which contains a high percentage of clay.

3. Ellsworth silt loam, 17–28 inches, pH 4.45.—These results are given in Fig. 4. The order of flocculation was Mn, original soil, H, Mg, Ca, K, and Na. Here again, the Mn ion has produced a marked

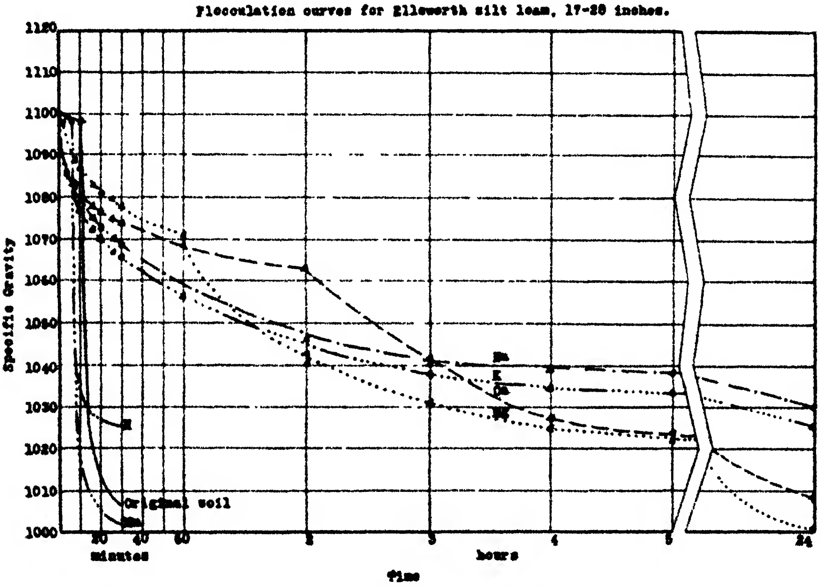

FIG. 4.

flocculating action. The original soil flocculated almost as rapidly as the one saturated with the Mn ion. It is interesting to note the comparison of the original soil and the one saturated with the H ion. The reaction of the former is pH 4.45, that of the latter pH 3.11. However, the increase in acidity has decreased the state of flocculation.

4. Ellsworth silt loam, 28–40 inches, pH 5.30.—Fig. 5 shows the state of flocculation of these suspensions. The order is Mg, Mn, original soil, H, Ca, K, and Na. The Mg ion has produced an abnormal flocculation, probably due to the slight decrease in the pH value of the suspension. There is the same correlation between the original soil and the one saturated with Mn as in the other horizon of the Ellsworth.

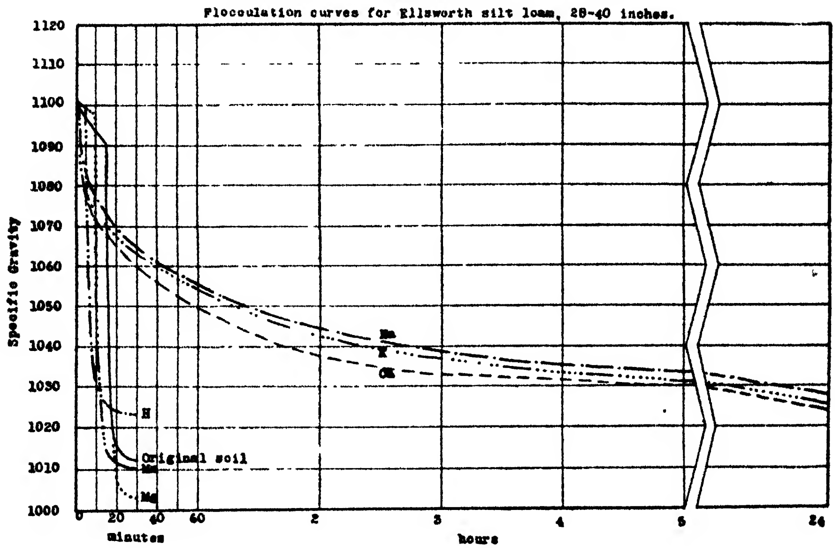

FIG. 5.

5. Clermont silt loam, 0–8 inches, pH 4.90.—These results are shown in Fig. 6. In the case of this silt loam, it is interesting to note that only the original soil appears to be flocculated. However, in measuring the reaction of the soil saturated with Mn, it was observed to be pH 7.05. The reaction of the other soils saturated with

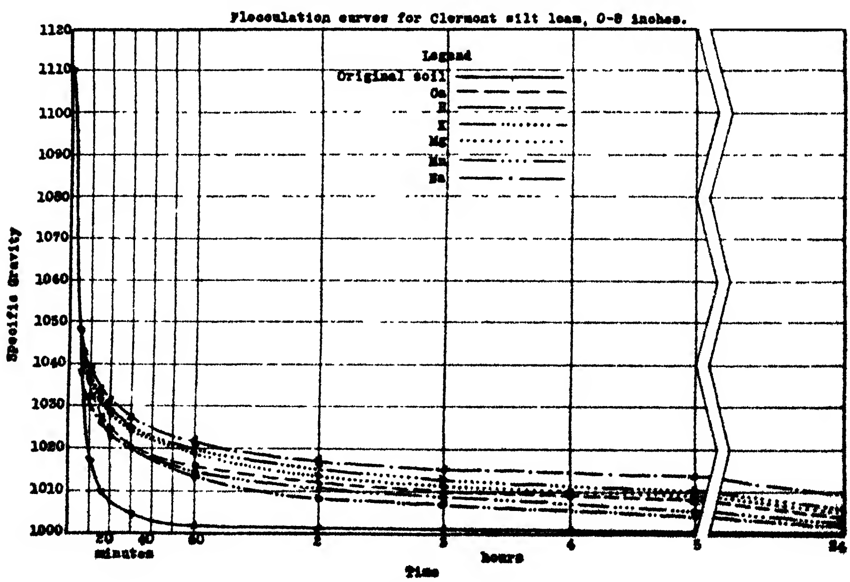

FIG. 6.

Mn varied from pH 6.15 to pH 6.70. Flocculation occurred in all these suspensions. Flocculation of the Clermont silt loam saturated with Mn was produced by the addition of a drop of acid to the suspension. Likewise, flocculation of the H-saturated suspension was produced by the addition of several crystals of manganese acetate. This tends to show a specific flocculating action of the Mn ion below the neutral point. This phenomenon is being further investigated.

These flocculation studies show several significant effects produced by the different ions under the conditions of the experiment. The Ca ion has had a decided flocculating action on the soils containing a rather high percentage of clay. Its flocculating action has decreased in soils containing more silt and less clay. The Mn ion has exhibited a strong flocculating action, with the exception of the Clermont silt loam whose reaction was pH 7.05. This slight decrease in acidity evidently has affected the coagulation value of the suspension.

Bradfield (4) states that the coagulation value of a colloidal clay, may vary considerably with a slight change in the H-ion concentration. The H-saturated soils were always less flocculated than the original, untreated soil. The coarser particles appeared to be flocculated, although the colloidal material seems to have been peptized to some extent. This is in accord with the views of Gedroiz (11). The Na and K ions have exerted an apparent deflocculation action on all the suspensions.

Undoubtedly, there are several factors involved in the flocculation of these suspensions which may account for the results. Flocculation may be dependent upon the reaction, concentration of the suspensions, the presence of protective colloids, etc. The effect of these factors requires additional investigation.

RATE OF SLAKING

When a "lump" of soil is immersed in a large volume of water it gradually disintegrates and finally falls into a soft mass. This phenomenon is known as "slaking." The time required for any soil to slake will vary according to its porosity and to the cohesion of the particles. Bouyoucos (5, 7) states that slaking depends upon the rate at which the water is absorbed by or penetrates the soil mass, the swelling of the soil colloids, and the cohesion of the soil particles.

The method followed in studying the slaking of soils consisted of placing small dry balls of soils on a wire screen immersed in about 400 cc of water and observing the time required for the complete disintegration of the balls. These balls were made by mixing 10 grams of soil with sufficient water to form a plastic mass that could be

kneaded and rolled into a ball, having a smooth surface, between the palms of the hands. They were dried at room temperatures for four days.

The results given in Table 4, Column 9, show that there is a large difference in the time of slaking, not only with the different types of soil used, but also with the soils saturated with the different cations. This time varies from 6 minutes with the untreated Clermont silt loam to 10 hours with the Na-saturated Toledo silty clay, 14–18 inches. The untreated soils containing a large percentage of clay and colloidal material slaked much more slowly than those with only a small amount of clay. The H ion has increased the rate of disintegration, the increase being greater with the heavier textured soils. The Na and K ions have decreased the rate of disintegration, Na exerting the greater diminishing effect. This increase in the time required for complete disintegration was due to the slow rate at which the water penetrated the soil and to an apparently strong cohesion of the soil particles. The other cations produced no significant changes in the rate of slaking.

The slaked material was distinctly granular in structure with the H-saturated soils and granular to flaky with the soils saturated with the divalent cations. The K-saturated soils disintegrated into coarse irregular clumps, either approaching a coarse platy or a very coarse granular structure. The soil saturated with Na disintegrated into single grains. The ball would swell upon the absorption of water, becoming very gelatinous in nature. Cracks were produced in those soils containing much colloidal material. The slaked material was distinctly gelatinous.

PLASTICITY COEFFICIENTS

The Atterberg plasticity constants afford a means of determining the plasticity of soils under certain conditions of moisture. They are being used as an expression of the consistency of soils, that is, the term "expressing the degree of cohesion of the soil and the resistance opposed to forces tending to deform or rupture the aggregates." Plasticity of soils is regulated by the size, shape, internal structure, and aggregation of the solid particles. The presence or absence of colloidal material, organic or inorganic, will act towards increased or decreased plasticity, respectively. We can picture the colloidal material in the soil acting as a lubricant between the coarse particles, allowing them to slide over each other, thereby producing plasticity.

De Sigmond (9) states that the "gel-colloids are insoluble in water but form a fine dispersion or sol. These sols have a viscosity greater

than water, therefore they behave like oil in a machine, diminishing the friction between the soil particles. Now, as plasticity can be explained by supposing that (between the limits of plasticity) the friction of the soil particles is smaller than the cohesion of the soil particles, we can easily understand that such colloidal solutions increase the plasticity when diminishing the friction of the soil particles." Rohland, cited by Searle (21), regards plastic clay as consisting of non-plastic particles surrounded by films of colloidal material, these films being saturated when maximum plasticity is produced. When the clay becomes dry the colloidal material shrinks

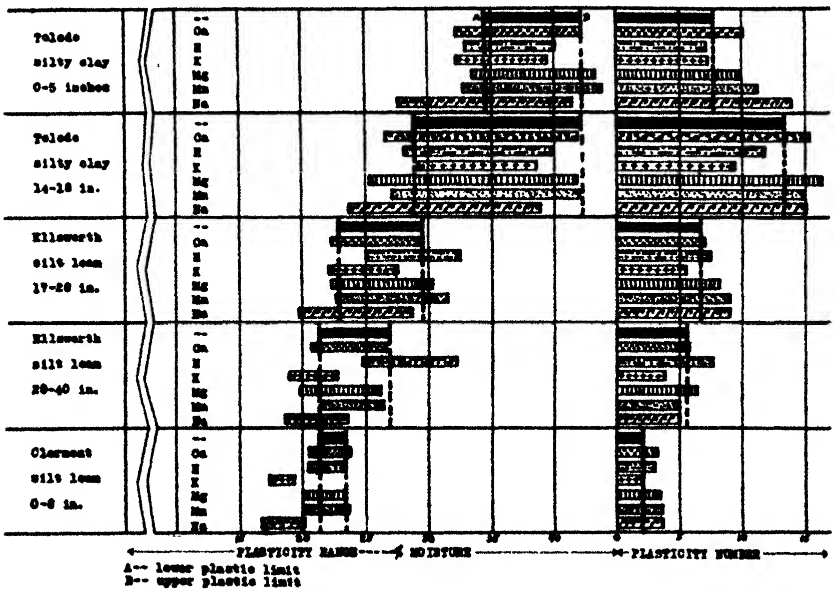

Fig. 7.

and becomes horny and the particles cannot move over each other. Searle (21) states that plasticity is not wholly due to the small size of the particles nor directly connected with the chemical composition of the material. However, the chemical and physical nature of the colloids probably plays an important rôle in the plasticity of soils.

The constants used in expressing the consistency of soils on this basis, according to Atterberg (2, 3) and Russell and Wehr (20), are as follows: the lower plastic limit, that moisture content at which the soil can barely be rolled into a wire; the upper plastic limit, that moisture content at which the soil can barely be made to flow under a certain force; and, the plasticity number, which is the difference between the two plastic limits.

The results showing the relation of exchange cations to these plasticity coefficients are shown in Table 1, Columns 2, 3, and 4, and in Fig. 7. These data show that there is a tendency for the divalent ions to increase the plasticity number. This increase is either due to the lowering of the lower plastic limit, or a raising of the upper plastic limit, or both. There are no consistent variations in regard to the changing of these plastic limits.

The Na ion has lowered both limits in every soil, at the same time, with one exception, increasing the plasticity number. This increase in the plasticity number is due to the high dispersive action of the Na ion which lowers the lower plastic limit considerably. Searle (21) reports that the addition of alkali usually decreases the amount of water necessary to develop plasticity. De Sigmond (9) states that the Hungarian alkali or "szik" soils have considerable plasticity.

The K ion has exerted a very specific effect on the plasticity constants. The soils saturated with K have the lowest plasticity numbers. This decrease has been brought about by a very decided lowering of the upper plastic limit with a slight decrease in the lower plastic limit. In the Clermont silt loam, the plasticity range on the moisture scale of the K-saturated soil has been moved entirely below that of the original soil. Dorfner, cited by Searle (21), found that the lower the proportion of potash in a clay, the more plastic the material will be.

The H ion has produced two different effects in the various types of soils used. In the Toledo silty clay, a soil with a relatively high degree of saturation, the H ion has lowered the plasticity number by lowering the upper plastic limit. In the Ellsworth and Clermont silt loams, with a lower degree of saturation, the plasticity number has been increased. Both plastic limits have been affected. The different action under these two conditions is probably due to differences in the degree of saturation. Schurecht, cited by Searle (21), found that acids in small quantities increased the water required to develop plasticity, but larger amounts decreased it.

In order to show the specific effect of the K ion on the plasticity constants, the H-saturated soil from the 17–28 inch horizon of the Ellsworth silt loam was saturated with the K ion. The effect was a large decrease in the plasticity caused by a decided lowering of both plastic limits. On the other hand, the K-saturated soil from the same horizon was saturated with the H ion. The plasticity number was increased and the plastic limits raised on the moisture scale. The K ion lowered the plasticity range beyond that of the H-saturated soil. The H ion raised the plasticity range above that occupied by the soil saturated with the K ion. These results are given in Table 5.

TABLE 5.—*Specific effect of the K and H ions on the plasticity coefficients of Ellsworth silt loam, 17–28 inches.*

Treatment	Plasticity range, % moisture Lower limit	Upper limit	Plasticity Number
None	22.90	29.50	6.60
Soil saturated with H	25.00	32.56	7.56
Soil saturated with K	22.14	27.60	5.46
Soil saturated with H then H replaced by K	18.85	20.98	2.13
Soil saturated with K then K replaced by H	22.74	31.19	8.45

SUMMARY

These investigations show that there is a decided relationship existing between the exchange cations on the soil-absorbing complex and its physical properties.

The following effects of the different ions were observed:

1. The Ca ion produced no significant effect on the moisture equivalent, hygroscopic coefficient, and heat of wetting. It had a marked flocculating action on soils containing a high percentage of clay. It had a tendency to increase the plasticity number of the soil.

2. The K ion produced no significant change in the moisture equivalent value. It decreased the hygroscopic coefficient determined over 2% and 30% H_2SO_4 as well as the heat of wetting. It had a deflocculating effect on the soil suspension. It lowered the plasticity number of all the soils. Both plastic limits were lowered.

3. The H ion showed no effect on the moisture equivalent, hygroscopic coefficient, and heat of wetting. It caused a decrease in the state of flocculation of the soil suspensions. In soils highly saturated with bases it decreased the plasticity number. The plasticity number was increased in soils with a low degree of saturation.

4. The Mg ion showed no marked effect on the moisture equivalent, hygroscopic coefficient, or heat of wetting. It decreased, with one exception, the state of flocculation. It had a tendency to increase the plasticity number.

5. The Mn ion produced no significant effect on the moisture equivalent, hygroscopic coefficient, and heat of wetting. It produced a strong flocculating action below the neutral point. There was a slight tendency towards an increase in the plasticity number.

6. The Na ion increased the moisture equivalent, due to the highly puddled condition of the soil. It decreased the hygroscopic coefficient as determined over 30% H_2SO_4, as well as the heat of wetting. It had no pronounced effect on the hygroscopic coefficient

with 2% acid. It caused a deflocculation of the soil suspensions. It increased the plasticity number of the soil by lowering the lower plastic limit.

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THE INTENSIVE PRODUCTION OF SINGLE CROSSES BETWEEN SELFED LINES OF CORN FOR DOUBLE CROSSING[1]

FREDERICK D. RICHEY[2]

The practicability of F_1 crosses and double crosses between selfed lines of corn has been questioned on the basis of the difficulty of seed production and distribution. The difficulty of maintaining seed of two or four parent lines and producing the F_1 seed of a single cross, or of two single crosses and a double cross, each year seems almost insuperable to those unfamiliar with the ease of obtaining hand-pollinated ears of corn. One accustomed to hand pollinating corn, however, naturally would rely on this procedure in maintaining the parent lines and, if the ultimate objective were a double cross, in making the single crosses. Isolation then would be needed only for the larger plat in which is grown the seed to be sold or used in the commercial fields.

With this in mind, it seemed worthwhile to obtain data on the labor involved in maintaining parent lines and obtaining F_1 crossed seed by hand pollinating necessary to a small continuous production of double crossed seed for commercial use. The writer accordingly obtained such data in 1927, and these are presented here.

The parent lines may be designated 227-2-S_6, 227-3-S_6, 228-4-8-S_7, and 228-6-5-S_7. In these pedigrees, 227 and 228 are the Cereal Investigations accession numbers. No. 227 was a sample of a bloody butcher type of dent corn from the Chinese exhibit at the San Francisco Exposition. No. 228 was a single ear of the Lancaster Surecrop variety grown in Illinois. The 2, 3, 4-8, and 6-5 in the pedigrees are the strain numbers, and the subscripts to S show the numbers of selfed generations through which selection has been practiced. The objective was to maintain these four strains on a small scale and to produce the two single crosses 227-3 x 2 and 228-4-8 x 6-5. It was hoped to carry the work through in 1928 by actually producing seed of the double cross (228-4-8 x 6-5) x (227-3 x 2). Unfortunately, the single crosses and the double cross were not good enough when tested in 1927 in the section where the double crossing was to be done to warrant undertaking this phase.

The corn was grown in the backyard at the writer's residence in Chevy Chase, Md., on a clay soil some of which had come from the excavation for the basement of said residence in the fall of 1924.

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication May 31, 1928.

[2]Agronomist in Charge of Corn Investigations.

The limited area available necessitated thick planting (Fig. 1). Twelve rows 3 feet apart and from about 15 to 18 feet long were planted. Two kernels were planted every 8 inches in the row, the plat being thinned later to one plant in a place. Thus, something more than 300 plants were grown on approximately 600 square feet, or about 22,000 plants per acre.

The corn was planted in shallow furrows on May 20. Nitrate of soda was applied at a rate of about 50 pounds per acre during emergence and at a rate of 100 pounds per acre on June 15. Superphosphate (acid phosphate) at a rate of some 400 pounds per acre also was applied on June 15. The plat was irrigated thoroughly on two occasions when this seemed desirable. Good rains occurred shortly after each irrigation.

FIG. 1.—Some 300 plants of selfed lines of corn from which enough hand-pollinated crossed seed was obtained to plant a 5-acre double crossing field.

There were three rows of 227-3 and seven rows of 228-4-8 in which plants were to be selfed and crossed, and one row each of 227-2 and 228-6-5 to be selfed and to furnish pollen. The first few plants of 227-3 and 228-4-8 to silk were selfed or sib-pollinated. After this, the tassels were removed from the plants of these strains to reduce the amount of random pollen. All shoots were bagged with small glassine bags before any silks had emerged. After the first silks of a shoot had emerged, the shoot was cut back 1 or 2 inches and pollinated one or two days later. Pollen was used only from tassels that had been bagged at least over night.

Tasselling began sporadically July 31. By August 3, about three-fourths of the tassels in 228-4-8 were shedding pollen and a few in 228-6-5 were beginning to shed. The tassels in 227-3 were well out but not shedding at this time and those in 227-2 were just beginning

to show. A few shoots were bagged on July 30, the first silks appearing on August 2. Some 5 to 30 minutes daily were required to bag shoots and tassels between August 1 and 5. The first pollinations were made on August 6, when about 1½ hours were spent in the plat. The approximate time spent in the plat on each of the days from August 6 to 16, when pollination was completed, except for a few individualistic plants, and the number of pollinations completed each day are shown in Table 1.

TABLE 1.—*Time spent in pollinating and number of pollinations made daily in 12 rows of corn at Chevy Chase, Md., in 1927.*

Date, August	Time (hours)	Pollinations made in the rows stated												
		1	2	3	4	5	6	7	8	9	10	11	12	Total
6	1.5	1	1	1	0	4	0	1	0	0	6	2	0	16
7	3.0	3	0	2	0	3	5	4	7	11	8	8	3	54
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1.5	0	0	1	4	5	0	0	0	1	1	0	0	12
10	2.5	2	3	3	1	7	10	10	10	7	12	8	11	84
11	1.5	0	1	4	5	0	6	6	3	5	2	3	4	39
12	0.5	0	4	0	2	0	0	1	2	0	0	2	2	13
13	0.5	3	0	3	2	1	1	4	2	1	0	1	1	19
14	1	3	6	5	4	1	1	2	1	0	0	2	3	28
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0.2	1	2	1	4	0	2	1	0	1	0	1	0	13
Total	12.2	13	17	20	22	21	25	29	25	26	29	27	24	278

The corn was harvested about October 1. Of the 278 pollinations made, 260 resulted in ears good enough to save for seed. Selected ears of each strain are shown in Fig. 2. The number of ears of each class and the estimated number of sound kernels are shown in Table 2. The estimated number of kernels is based on approximately 200 per ear, something less than the number indicated by counts of several representative ears.

TABLE 2.—*The number of hand-pollinated ears in the different strains and the estimated total number of seeds of each class produced in a plat of approximately 300 corn plants at Chevy Chase, Md., in 1927.*

Parent strains		Number of	
Pistillate	Staminate	Ears	Kernels
228-4-8	228-6-5	153	30,000
228-4-8	Self	20	4,000
228-6-5	Self	21	4,000
227-3	227-2	36	7,500
227-3	Self	10	2,000
227-2	Self	20	4,000

The selfed ears would provide a superabundance of seed for continuing the parent lines and for obtaining F_1 crosses in the next

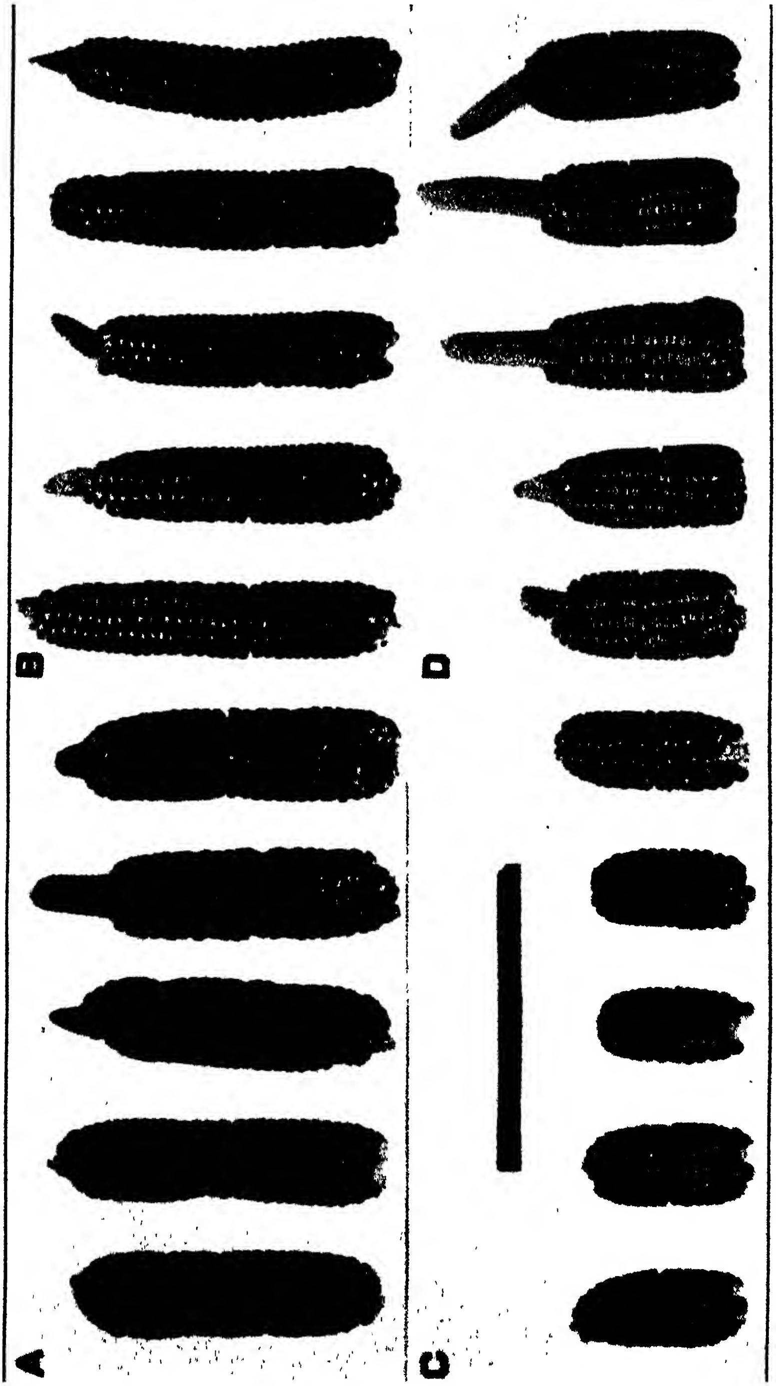

FIG. 2.—Five representative hand-pollinated ears of lines 228–4–8 (A), 228–6–5 (B), 227–2 (C), and 227–3 (D) from the plants shown in Fig. 1.

year. Enough of the two crosses is available to plant 5 acres at 7,500 seeds per acre, and having four rows of 228–4–8 x 6–5 for detasselling to each row of 227–3 x 2 for furnishing pollen. On this basis 4 acres would be devoted to actual seed production. The acre yield from 228–4–8 x 6–5 should not be less than 50 bushels under reasonably good conditions. In other words, some 12 hours distributed over 11 days and devoted to hand pollinating in a 600 square foot plat of corn was enough to maintain the parent strains and produce seed of single crosses sufficient for producing some 200 bushels of double-crossed seed corn. Certainly this is not prohibitive in so far as this phase of seed production is concerned.

The use of F_1 crosses or double crosses between selfed lines of corn promises large increases in acre yields just as soon as productive combinations are found for the different corn-producing areas. One voiced criticism of the use of crossed seed corn is the claimed impracticability of seed production and distribution. It is recognized that this presents difficulties. It should be recognized that these difficulties also may offer advantages in the way of affording a rational basis for inspecting and certifying seed corn. Such certification, if on a sound basis of germinal stability, not only promotes a wider use of more productive sorts, but also promotes the use of seed of better germinating power.

The present study was undertaken primarily to determine the labor involved in growing the single crosses necessary for producing double crossed seed on a small scale, such as an individual farmer might find profitable in supplying local needs. The difficulties were increased by the need for crowding and by other unfavorable conditions. Nevertheless, labor involved was negligible if charged against the potential 200 bushels of double crossed seed that could be grown from the single crosses obtained. The major item of expense in producing double crossed seed will of course be in detasselling in the large field where the commercial seed is produced. It is regretted that it seemed inadvisable to carry this study through that phase of production also. Reliable information on this is needed and it is to be hoped that it will be supplied.

REDUCTION OF SOIL NITRATES DURING THE GROWTH OF SOYBEANS[1]

E. P. DEATRICK[2]

INTRODUCTION

Within recent years the growing of soybeans in West Virginia has increased considerably. With this increased acreage there have been received lately a number of complaints that the yield of wheat following soybeans is decreased below that normally secured. A cursory review of the field data does not reveal this reported detrimental effect on wheat yields to any great extent. For instance, Slipher (5)[3] collected data on wheat yields from various sources. He reports seven cases. Five of these show increases of from 2 to 7 bushels per acre more wheat after soybeans than after wheat, oats, and corn. In but two of the cases are there no increases. One of these indicates no increase, and the other a yield of 10 bushels less wheat after soybeans than after clover.

A pamphlet (6) issued for the Maryland Field Day of the National Soybean Growers' Association in 1925 contains data secured from three Maryland fields showing that wheat increases are greater after soybeans than after corn. Although the majority of the results reporting yields of wheat after soybeans would seem to indicate that the decreased yields complained of in West Virginia are the exception, there is not a complete uniformity in the results reported.

Since the relatively high nitrogen content of soybean hay indicates a high nitrogen absorption, it was conjectured that possibly nitrogen assimilation by the soybean plants progresses until the nitrate nitrogen content of the soil is very low, and a consequent effect is one of lowering the yield of the wheat that follows. It was decided, therefore, to study the nitrate content of soil growing soybeans under controlled conditions, and accordingly investigations were started in the greenhouse in 1925.

METHOD

Dekalb silt loam from an area just bordering the horticulture farm, which to all indications had never been cropped nor fertilized, was air dried and thoroughly mixed. A screened amount of soil sufficient to

[1]Contribution from the Department of Soils, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Approved as Scientific Paper No. 59 by the Director of the Station. Received for publication June 4, 1928.

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[3]Reference by number is to "Literature Cited," p. 958.

fill 150 4-gallon crocks, having been secured, 13 kilograms were put into each crock. The ordinary straight-sided glazed crocks were used, a drainage hole was drilled through the bottom, and two Livingston auto-irrigators were inserted. Forty of the soils were kept air dry, while 110 were wet up to an optimum of 30% of the air-dry weight of the soil. This was accomplished (1) by raising the supply water[4] reservoir 6 or 7 feet above the cones, thereby causing water to be forced out through the pores of the cones into the soil. When the surface began to become damp, the overhead supply was cut off and the soil was then supplied with water drawn from the bottles which were placed either 4 feet below the cones or at a more convenient height, in which case a monometer, containing mercury sufficient just to hold back a flow of water under a head of 4 feet was put in the water line. When the supply bottle was thus arranged, the amount of water in the soil remained constant, provided the irrigator system was kept free of leaks. A test pot weighing a total of 24,950 grams was set upon the platform of a large Troemner balance in the greenhouse. From May 14 to May 26 the weight of the pot varied within a range of not more than 40 grams. No attention was given the system except that the pot was weighed once each day. When the supply bottle was hooked up with a large number of pots (in these trials a 5-gallon bottle supplied 30 pots), it was necessary to force air out of the tubing and cones whenever the capillary system broke. This sometimes required an hour's time two or three times a week. It was thus possible to water this large number of potted soils uniformly, with a minimum of labor. The drainage hole was plugged with a one-hole stopper fitted with a glass tube. A short piece of rubber tubing was attached so that a plug could be inserted when the soils were being wet up for the taking of drainage samples. All drainage tubes were left open at other times and the pots never drained any water in the intervals between the times of taking drainage samples This showed that an excess of water had not been regularly supplied during these intervals.

Considerable difficulty was encountered in securing uniform drainage samples. It was found that flooding the crocks from the surface, and collecting samples after two or three days were allowed for equilibrium to be established, was not very satisfactory. There, now, is evidence that a better method of securing drainage samples is to allow the soils to increase in moisture content, by taking the mercury out of the manometer until the desired amount of percolation water is obtained. The drainage tube should then be plugged,

[4]Distilled water was used throughout because of nitrogen in the tap water.

the water supply shut off, and the collected sample poured onto the surface of the soil. After waiting a day for equilibrium to take place, the drainage sample may finally be collected and analyzed. The checking of the nitrate determinations[5] of the drainage waters from pots of replicated treatments is not so close as is desired. This is undoubtedly caused mostly by an unequal dilution of the soil solutions. It is likely, also, that some of the variability was caused by failure to maintain absolutely uniform wetting of the soil. The data with which this paper deals were collected before the better method[6] for watering soils with auto-irrigators was worked out. Notwithstanding these discrepancies, ranges of the order of 0-20, 50-250, 300-900, and 1,000-2,000 of nitrates in p. p. m. are sufficiently separate to warrant the publication of this preliminary report.

The general plan of the work was interrupted several times and it was not until 1927 that the entire plan shown in Table 1 could be followed. In brief, then, the tests as carried out in 1927 were as follows: After the 150 4-gallon pots were set up, 40, as mentioned, were not connected with the water system and the soils were left air dry. The soils in the 110 pots were wetted, limed at the rate of 2 tons per acre, and four soybeans (Wilson) that were just germinating were coated with an inoculum of *B. radicicola* of soybean and planted. When the seeds were just forming in the pod, the soybean tops were cut close to the soil, dried, and ground. The ground soybean tops

TABLE 1.—*Plan of experiment.*

A. Wheat seeded immediately after soybean harvest.

a. Soybean tops removed.	b. Soybean tops turned under.
1. Check, no treatment.	5. Check, no treatment.
2. 200 pounds $NaNO_3$ per acre	6. 200 pounds $NaNO_3$ per acre.
3. 50 pounds $NaNO_3$ per acre.	7. 50 pounds $NaNO_3$ per acre.
4. 8 tons manure per acre.	

B. Wheat planted eight weeks after soybean harvest.

a. Soybean tops removed.	b. Soybean tops turned under.
8. Check, no treatment.	9. Check, no treatment.

C. Wheat not planted after soybean harvest, soil bare.

a. Soybean tops removed.	b. Soybean tops turned under.
10. Check, no treatment.	11. Check, no treatment.

D. Wheat planted on soil left bare and air dry during growth of soybeans.

12. Check, no treatment.	13. 200 pounds $NaNO_3$ per acre.
14. 50 pounds $NaNO_3$ per acre.	15. 8 tons manure per acre.

[5]Nitrates were determined by the Phenol-disulfonic acid method.

[6]With as many as 750 rubber connections in the water system, the development of leaks became quite a problem, especially since the rubber deteriorates rapidly. A system is now being set up with the use of block tin, thus the T's leading to the individual pots can be soldered to the main lines and the number of rubber connections can be reduced to a minimum.

were mixed with the top 2 or 3 inches of soil of each of 50 pots. These 50 and the remaining 60 were divided into series of 10 pots each, thus making nine replications of each treatment. They were seeded to wheat and handled as shown in the plan given in Table 1.

RESULTS

The frequency distributions of the nitrate nitrogen determinations of the drainage from 100 potted soils growing soybeans are given in Table 2. In one-half month's time the reduction of nitrate nitrogen under maturing soybeans was sufficient to show up definitely. It was expected that the nitrate concentration of the drainage waters from the original stock soil could be determined by analyzing the drainage waters from the soil kept air dry during the period of the growth of the soybeans in the other pots. These air-dry soils were therefore wetted up when the soybeans in the other pots were harvested. But the drainage waters, collected within a week from the time when the wetting up commenced, were found to contain an unexpectedly high amount of nitrate nitrogen. Undoubtedly the fallowing under air-dry conditions had brought about a great change. Either the nitrates increased gradually[7] or some change was brought about which resulted in greatly increasing the rate of nitrification when the soils were finally wetted. Whatever the type of increase, the nitrate content of these waters could not, of course, be used as was planned in the calculation of the total reduction accompanying the growth of the soybeans.

TABLE 2.—*Frequency distributions, showing the reduction in the nitrate nitrogen concentration in one-half month's time in drainage waters from soil, both limed and inoculated in pots growing soybeans.*

Date	Age of beans	Frequency distribution of nitrates in p.p.m.					
		0 or trace	0.5–10	11–20	21–30	31–40	41–50
June 29......	2 months	54	27	14	1	3	1
July 15	2½ months	95	5	0	0	0	0

Inasmuch as improvements were desired in the irrigation system, the soil was allowed to dry, the irrigator cones were taken out, new connections were made, and the cones were replaced. When the soil was remoistened, all of it, except that in 40 of the pots which had grown soybeans, was seeded to wheat. This was done even tho it was fully realized that the fallowed soil was no longer the same as the stock soil which was planted to soybeans and that another factor was

[7]Work reported in the 40th Annual Report of the Nebraska Experiment Station indicates that "maintaining soil at a condition of dryness below the hygroscopic coefficient is stimulative to nitrification."

introduced by the drying out and aerating of the soil during the time of making changes in the irrigator system. Thus it is important that the data in Table 3 should be studied with these facts in mind. The "number of days delay in seeding wheat" in those soils not seeded immediately is therefore not the delay after harvesting soybeans, as was first planned, but the delay after the remoistening. It will be noted that, although the checking of replicated treatments is very poor, the nitrates from the soybean soil, regardless of the fertilizers that were added, are much lower than those from the fallowed soil. This is true both when the wheat is 18 and 25 days old. Further results on this crop of wheat could not be secured for in spite of all the care taken, the effect of powdery mildew during the excessively cloudy weather during November and December 1926 was too severe and the wheat died before it matured.

All of the soil was therefore taken out of the pots, dried, sieved, thoroughly mixed, and repotted. Soybeans (Wilson) were planted on June 16, 1927, in 110 pots after the soils were moistened. Drainage samples were secured as soon as possible. The frequency distributions of the nitrate determinations of this "stock soil" are given in Table 4. After the soybeans were harvested on August 22, 30 grams of the dried and ground soybean tops (the average amount of dry matter produced per pot) were turned under the surface 2 or 3 inches of the soil of 50 pots and wheat was seeded in accordance with the plan given in Table 1.

Drainage samples were collected from all of the potted soils on January 7, 1928. The frequency distributions of the determinations of the nitrate concentration of these samples are also shown in Table 4. The data indicate that the nitrate nitrogen in soils growing wheat which was seeded immediately after the soybeans were harvested is very low. This is the case even when nitrate of soda at the rate of 200 pounds per acre is applied in addition to the soybean tops that were turned under. Comparison with the data secured from the analyses of the drainage waters from the stock soil shows that the reduction in nitrates was several hundred p.p.m. The determinations of nitrates in the drainage from the pots in series 1, 2, 3, 4, 5, 6, and 7 checked remarkably well. There were no nitrates in the drainage waters from any of the 20 soils in series 2 and 4. Such close checking was not secured where the nitrates were more concentrated. This, it is felt, was due, as has been suggested, largely to an unequal dilution of the soil solutions. However, the nitrates in the soil which was left bare and in that which was not seeded to wheat for eight weeks were sufficiently greater than the nitrates in the

soil sown to wheat in 1926.

Soil	Series	Age of wheat seedlings in days	Number of days delay in seeding wheat[a]	Fertilizer added in addition to soybean tops	Frequency distribution of nitrates in p. p. m. in drainage waters 0–50	51–100	101–150	151–200	201–250	251–300	301–350	500	501–1,000	1,001–1,500	1,501–2,000	2,001
Soybean	1	18	0	None	–	1	3	4	1	–	–	–	–	–	–	–
	2	18	0	200 pounds $NaNO_3$	–	2	2	4	1	1	–	–	–	–	–	–
	3	18	0	100 pounds $NaNO_3$	–	2	4	1	2	0	1	–	–	–	–	–
	4	18	0	50 pounds $NaNO_3$	–	2	6	1	0	0	1	–	–	–	–	–
	5	18	0	4 tons manure	–	3	4	2	1	–	–	–	–	–	–	–
	6	18	0	8 tons manure	–	6	2	1	0	0	1	–	–	–	–	–
	7	11	7	None	–	–	6	2	0	1	1	–	–	–	–	–
	8	4	14	None	–	2	4	3	–	–	–	–	–	–	–	–
	9	Check	21	None	–	1	7	2	–	–	–	–	–	–	–	–
	10	Check	–	None	–	1	4	2	1	1	1	–	–	–	–	–
Fallow	11	18	0	None	–	–	–	–	–	–	–	–	4	3	1	2
	12	18	0	200 pounds $NaNO_3$	–	–	–	–	–	–	–	–	5	3	2	–
	13	18	0	100 pounds $NaNO_3$	–	–	–	–	–	–	–	–	5	4	0	1
	14	18	0	50 pounds $NaNO_3$	–	–	–	–	–	–	–	–	4	3	2	1
	15	18	0	8 tons manure	–	–	–	–	–	–	–	2	3	1	4	–
Soybean	1	25	0	None	1	2	4	3	–	–	–	–	–	–	–	–
	2	25	0	200 pounds $NaNO_3$	1	1	2	2	3	1	–	–	–	–	–	–
	3	25	0	100 pounds $NaNO_3$	2	1	1	3	3	–	–	–	–	–	–	–
	4	25	0	50 pounds $NaNO_3$	–	0	3	5	2	–	–	–	–	–	–	–
	5	25	0	4 tons manure	5	1	2	0	1	–	–	–	–	–	–	–
	6	25	0	8 tons manure	6	1	0	0	3	–	–	–	–	–	–	–
	7	18	7	None	2	0	3	1	4	–	–	–	–	–	–	–
	8	11	14	None	2	1	4	2	1	–	–	–	–	–	–	–
	9	4	21	None	–	1	6	2	1	–	–	–	–	–	–	–
	10	Check	–	None	–	0	3	5	0	0	1	–	–	–	–	–
Fallow	11	25	0	None	–	–	–	–	–	–	–	2	8	–	–	–
	12	25	0	200 pounds $NaNO_3$	–	–	–	–	–	–	–	2	8	–	–	–
	13	25	0	100 pounds $NaNO_3$	–	–	–	–	–	–	–	3	7	–	–	–
	14	25	0	50 pounds $NaNO_3$	–	–	–	–	–	–	–	2	8	–	–	–
	15	25	0	8 tons manure	–	–	–	–	–	–	–	3	7	–	–	–

TABLE 4.—*Frequency distributions, showing the nitrate nitrogen concentration in drainage waters from stock soil, fallow soil, and from soil seeded to wheat after soybeans.*

Series	Number of days between soybean harvest and wheat seeding	Soybean tops removed or turned under	Fertilizer treatment at wheat seeding time	Frequency distribution of nitrates in p. p. m. in drainage water											
				0–10	11–20	50–100	101–150	151–200	201–250	300–500	501–700	700–900	500–1,000	1,001–1,500	1,501–2,000
1	0	Removed	None	9	1	–	–	–	–	–	–	–	–	–	–
2	0	Removed	200 pounds $NaNO_3$	10	0	–	–	–	–	–	–	–	–	–	–
3	0	Removed	50 pounds $NaNO_3$	10	0	–	–	–	–	–	–	–	–	–	–
4	0	Removed	8 tons manure	10	0	–	–	–	–	–	–	–	–	–	–
5	0	Turned under	None	10	0	–	–	–	–	–	–	–	–	–	–
6	0	Turned under	200 pounds $NaNO_3$	10	0	–	–	–	–	–	–	–	–	–	–
7	0	Turned under	50 pounds $NaNO_3$	10	0	–	–	–	–	–	–	–	–	–	–
8	56	Removed	None	–	–	1	5	4	–	–	–	–	–	–	–
9	56	Turned under	None	–	–	1	2	5	2	–	–	–		–	–
10	56	Removed	None	–	–	–	2	8	–	–	–	–	–	–	–
11	56	Turned under	None	–	–	–	3	6	1	–	–	–	–	–	–
12	Stock soil	kept air dry	None	–	–	–	–	–	–	–	–	–	1	8	1
13	while soybeans	were	200 pounds $NaNO_3$	–	–	–	–	–	–	–	–	–	1	7	2
14	growing		50 pounds $NaNO_3$	–	–	–	–	–	–	–	–	–	1	8	1
15			8 tons manure	–	–	–	–	–	–	–	–	–	1	8	1
	Stock soil			–	–	–	–	–	–	39	60	11	–	–	–

soil which was seeded immediately to wheat to warrant a very definite conclusion. This is that a period allowing for the nitrification processes to build up nitrates in the soil between the time the soybeans are harvested and the wheat is seeded is more effective in increasing the nitrate concentration of the soil than is the application of nitrate of soda at the rate of 200 pounds per acre. The variability among the analyses of the drainage from pots in series 8, 9, 10, and 11 makes it unsafe to conclude, although the data suggest the possibility, that nitrate production is as great where the soybean tops are removed as where they are turned under. As indicated by the data secured in 1927 (Table 3), the analyses of the nitrate concentrations of the drainage waters from the fallowed soil show that fallowing in the air-dry condition has a greater effect on increasing the nitrate nitrogen content of this soil than the growing of soybeans.

Nitrate disappearance, as has often been pointed out, may be caused by plant absorption, or by microbiological assimilation, or by both. The high nitrogen content of the soybean would lead one to assume that plant absorption might be the main cause. That denitrification had not been stimulated is indicated at least by the data in Table 5 as well as by the fact that nitrates do reappear after the soybean harvest if the soil is not seeded to wheat immediately.

A 2% agar media was made up with waters drained from crocks that (a) had and (b) had not grown soybeans, series 1 and 12, Table 2. Fifteen hundred parts of NO_3 in the form of $NaNO_3$ were added to the series 1 drainage water to make the nitrate content equal in the two series. Some of the waters were sterilized in the autoclave, some distilled, and some were filtered through sterile porcelain filters before being added to the sterilized agar. The agar was poured into petri dishes and was inoculated with bits of cultures of *Fusarium semitectum*. The results are given in Table 5.

TABLE 5.—*Effect of drainage waters from soybean and no soybean soil on the growth of a denitrifier.*

"Soybean" drainage			"No soybean" drainage	
Water filtered	Water autoclaved	Water distilled and filtered	Water filtered	Water distilled
Growth	Growth	Growth	Growth	Growth

There did not seem to be any differential effect whatever. As *F. semitectum* is an unusually vigorous denitrifier, it is possible that other organisms tested in the same manner would yield different results.

DISCUSSION

Since soybeans have been grown extensively in West Virginia and have generally been considered a good legume crop to put in the rotation, the numerous reports from farmers in the state that the yields of wheat are at times decreased below normal when the wheat follows soybeans has led to experimentation under controlled conditions in the greenhouse. A careful investigation of reports from other states has also been made. As mentioned, a cursory review of the published data does not reveal complete uniformity in regard to the effect of soybeans on the yield of wheat that follows.

It is conjectured that the amount of nitrate nitrogen available at the time of planting the wheat is an important factor. Welton and Morris (7), Karraker (2), and others have confirmed the supposition of Lyon and Bizzell (3) that "the influence of a crop on nitrification may be an important factor in crop production." They have shown that there is a close relation between wheat yields and nitrates.

Since the results of greenhouse experiments reported here prove that the nitrate nitrogen content of the soil under maturing soybeans is very low, it was thought that this might be shown to be the case generally in the field, and that in a study of the length of the nitrification period before the wheat was seeded there might be found an explanation for the apparent lack in the uniformity of the results obtained after growing soybeans. Inasmuch as the desired information was not recorded, in all cases, in the publications reporting the data on wheat yields, this was secured by special correspondence. A study of the more complete data indicates that the results obtained in the greenhouse have been secured in the field and that the yield of wheat following soybeans is dependent upon such factors as (a) the state of growth of the soybeans and the dates when harvested, (b) the length of the nitrification interval between the harvest and the wheat planting, (c) the turning under of the tops, and (d) the application of fertilizers.

Sears (4) reports that the yields of wheat after soybeans cut for hay are greater than after soybeans that are cut for seed. In the former case the intervening nitrification period starts earlier when the season, as a rule, allows more intense nitrification to go on. This period is also likely to be longer than when soybeans are cut for seed. The length of time from the start of this period to the time when nitrification naturally decreases in the late fall is apparently a factor of considerable importance. The earlier the harvesting and the earlier this period of nitrification, the greater of course will be the amount of nitrates available for the wheat seedlings.

Welton and Morris (7) have plotted the amounts of nitrate nitrogen in the soil of soybean plats. The curves in all cases show a more or less steady decline in the amounts of nitrates after the middle of June. The lowest point is reached in September. When one superimposes marks indicating the dates of the soybean harvests, Sept. 22, 1921, Sept. 24, 1922, and Sept. 29, 1923 (secured from Welton), on these graphs, it is seen that the nitrates are very low at these times. In fact the superimposed marks either coincide with the lowest point of the curve or are just to one side of it. The work of Karraker (2), however, wherein he gives data showing that the amount of nitrates after soybeans is greater than that after tobacco, hemp, oats, or corn, seems to be at variance with the data from Ohio. It is reported that the nitrates are twice as high after soybeans as the next highest amount, that after oats. This apparent variance may be explained by the fact that the soybeans were harvested (according to Karraker) on September 12 and that the soil was sampled on October 10. The probable low point in the nitrate nitrogen content of the soil was therefore most likely missed and the large amounts of nitrate in the soil one month after harvesting the soybeans indicates that rapid nitrification of the soybean residues does take place if the season is not too late.

In Virginia, where according to Slipher's compilation 3.5 bushels more wheat were obtained after soybeans than after wheat, it is reported (by Hutcheson) that "the soybeans were cut off early in September and the wheat was seeded about October 1," thus allowing about one month for nitrification.

The increased yields of wheat after soybeans at the Maryland Station (6) were obtained when the soybeans were cut for hay and the period intervening between the harvest of the soybeans and the seeding of the wheat, which allowed the residues to be partly nitrified, was about a month. Other results (writes Metzger) show that decreased yields have been secured when the wheat followed soybeans cut for seed and when therefore this intervening period was shorter. The nitrate content of both of the soybean plats reported by Lyon and Bizzell (3) are lower than that of the check plats. On September 10 the nitrate content of the soil planted to soybeans on July 5 was lower than that of the soil planted July 24. Thus, both the stage of the growth of the soybeans and the length and earliness of the nitrification period seem to be important factors.

The largest increase in the yield of wheat after soybeans reported by Slipher (5) is 7 bushels. These data come from the Indiana Station. While, as Wiancko states, the wheat is seeded "right after

harvesting the soybeans," he also writes "very early in our rotation experiments we found that it was as necessary to have some readily available nitrogen in the fertilizer for wheat after soybeans as after corn in order to give it an equal start in the fall. Apparently the nitrogen in the soybean residues does not become available fast enough to do the wheat much good in the fall." Thus, the largest increase reported was secured when the soil was fertilized with nitrogen in the fall to give it a good start.

SUMMARY

With the increased growing of soybeans in West Virginia, numerous instances have been reported in which decreased yields of wheat are obtained when the wheat immediately follows the soybeans. An investigation of the reports of wheat yields after soybeans obtained at various stations has led to the assumption that the nitrification period in the fall between the harvesting of the soybeans and the planting of the wheat is an important factor. Where wheat is benefited this period is in many cases of considerable length.

Experiments with potted soils are described and data are given to show that the nitrates under maturing soybeans are very low. At the time of harvest the nitrates in fallow soil (kept air dry) are considerably greater than under soybeans. The drainage water from both the soybeans and fallow soil did not affect the relative growth of a vigorous denitrifying fungus.

CONCLUSIONS

1. It is concluded that nitrates in soils under maturing soybeans are very low.

2. When the soybean harvest is so late that the period between the harvest and the planting of the wheat is too short to allow for considerable nitrification, the supply of nitrates is apparently too low to produce an increase in the yield above normal.

3. The decrease in nitrates is thought to be largely due to absorption by the plant.

4. Where it is desired to follow soybeans with winter wheat in a rotation, it appears advisable to plant soybeans of shorter growing periods so as to allow for longer intervals for nitrification in the soil before the planting of the wheat.

5. The results of the pot work indicate that a long period for nitrification is more beneficial than top dressings of 200 pounds of nitrate of soda or 8 tons of manure per acre, regardless of whether the soybean tops are removed or not.

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SOME FACTORS WHICH AFFECT THE INOCULATION OF SOYBEANS[1]

Horace J. Harper and Henry F. Murphy[2]

Although a considerable number of investigations have been made in regard to the inoculation of soybeans, there still seems to be some difference of opinion among investigators in regard to certain factors which may affect nodule formation and to the various effects which may be produced by the association of the bacteria with the soybean plants. As a result of field observations made by the authors during the past few years, there appeared to be certain factors affecting the successful inoculation of soybeans that did not seem to be emphasized in the literature. Consequently, this investigation was planned to determine, if possible, what factors were most important in preventing satisfactory inoculation, particularly under the climatic conditions which exist in Oklahoma.

REVIEW OF LITERATURE

A review of the literature on the inoculation of soybean plants indicates that there are several factors, one or all of which may often affect nodule formation. Most of the factors which have been studied can be divided into three main groups as follows:

1. Virility and specificity of the organism or resistance of the plant to infection.
2. Composition and concentration of the soil solution.
3. Moisture relationships in the soil.

Most investigators will agree that the vitality of the organisms will decrease under unfavorable conditions, but there is some difference of opinion in regard to the resistance of different varieties of soybeans to infection.

Voorhees (15)[3] and Morse (10) report instances where certain varieties of soybeans treated with the same bacteria as other varieties and grown under similar conditions failed to produce nodules, while other varieties growing in adjacent rows had an abundance of nodules on their roots. Fred and Bryan (2) and Fred, Whiting, and Hastings (4) state that of all the varieties of soybeans which they studied, bacteria isolated from the nodules of one variety would infect all of the other varieties. Wright (18) has recently shown that there are at least two distinct types of soybean organisms. One type produces nodules principally on the tap root and the other type produces

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[3]Reference by number is to "Literature Cited," p. 974.

nodules chiefly on the fibrous roots. Sears and Carroll (13) state that some strains of bacteria selected from cowpea nodules will infect soybean roots, while other strains from cowpeas will not cause infection on soybeans. All cultures isolated from soybeans produced nodules on the roots of cowpeas.

The effect of different salts on soybean inoculation has been studied by several investigators. It has been found that the presence of large amounts of nitrates (6, 9, 14) are unfavorable for nodule formation. Fred and Graul (3) believe that most soils do not usually contain sufficient amounts of nitrate to inhibit nodule production, although Strowd (14) has shown that plants grown in a soil containing nitrates will have a much higher concentration of nitrate in their cell sap than that which is present in the soil.

The addition of phosphorus and potash to a poor sandy soil growing soybeans produced an increase in nitrogen fixation according to Lipman and Blair (8). Scanlan (12), Perkins (11), and others report that in their studies the essential plant foods have had little influence on nodule formation. Wilson (17) and Scanlan (12) state that the presence of calcium in the soil solution produced a marked increase in nodule formation. Several other substances have also been found which seem to increase the production of nodules when added to the inoculated seed just prior to planting.

The effect of soil moisture on nodule formation has been studied by Gain (5), Moore (9), Perkins (11), and Wilson (17). They found that soybeans grown in soils maintained at a low moisture content produced fewer nodules than when similar plants were grown in soils which were kept at a high moisture content. Moore (9) states that drought is not fatal to the bacteria and other investigators have suggested that the cause for poor inoculation in soils kept at a low moisture content was that the bacteria could not move about and come in contact with the root-hairs. Fred and Bryan (2) state that the bacteria soon die when allowed to dry on the seed, and to avoid this the soybeans should be planted immediately. They also state that the age of the plant seems to influence the amount of infection and this would be true probably in case of Wright's Type A organisms which seem to infect the tap roots and on which the root-hairs disappear in a short period of time.

One other phase of this problem has been studied which is indirectly connected with nodule formation and that is whether or not soybean bacteria are always symbiotic in their relations with the host. Moore (9) found that soybean bacteria under certain conditions may be detrimental to the soybean plant, while Göbel (6) believes that

there is no struggle between the bacteria and the host. Most of the analyses which appear in the literature show that inoculated soybeans contain a higher percentage of nitrogen than uninoculated soybeans. This would not prove, however, that there is no struggle between the host and bacteria during a portion of the life cycle of the bacteria and plant.

RESULTS OF EXPERIMENTS

Because of the fact that many reports were received from farmers who had not been able to find many nodules on the roots of their soybean plants, several experiments were conducted to determine if possible what factors were most important in causing this difficulty.

In the first experiment, the results of which are given in Table 1, a study was made of the ability of different cultures of soybean bacteria to produce nodules on soybeans grown under different soil conditions. Virginia soybeans were used in this test and the seed was treated with the different cultures according to the directions printed on the containers in which each culture was received and was planted within a few hours after treatment. In case of the treatments marked "heavy" in Table 1 enough inoculating material for 1 bushel of seed was mixed with soil and scattered in a furrow 1 rod long. Soybeans were planted in the furrow so that the seed would be in contact with the soil containing the soybean bacteria. The heavy rate of inoculation was only studied on the Kirkland silt loam. The soil culture was applied at the rate of 1 pint of soil for each bushel of seed, however, not all the soil adhered to the seed.

Although there was a considerable difference in the ability of the different cultures to produce nodules, one of the main reasons for including these data was to show the difference between the formation of nodules on soybeans treated with the same bacteria but planted on different soil types. As a result of climatic and topographical conditions, an abundance of moisture was present in the Bates and Yahola soils at the time the soybeans were planted, while the Kirkland soil was low in moisture content, although enough moisture was present in the surface soil to germinate the seed. The subsurface soil contained a sufficient amount of water to promote the early growth of the plants which did not receive any rain for 10 days after planting. Good inoculation was secured on the Bates and Yahola soils with some of the cultures, but all cultures produced poor inoculation on the Kirkland silt loam. Even where a large amount of inoculating material was placed in contact with the soybean seed only a very small increase occurred in the average number of nodules per plant.

TABLE 1.—*Viability of different cultures for the inoculation of Virginia soybeans.*

No.	Culture used	Yahola sandy loam: Number plants studied	Yahola sandy loam: Percentage inoculation	Yahola sandy loam: Average number of nodules per plant	Kirkland silt loam: Number plants studied	Kirkland silt loam: Percentage inoculation	Kirkland silt loam: Average number nodules per plant	Bates sandy loam: Number plants studied	Bates sandy loam: Percentage inoculation	Bates sandy loam: Average number nodules per plant
1	Uninoculated	61	6	2.50	42	38	1.31	50	6	1.33
2	DeQueen	—	—	—	34	29	1.30	50	70	6.28
3	DeQueen (heavy)[a]	—	—	—	33	79	2.84	—	—	—
4	Nitragin	83	89	10.87	32	53	2.05	47	92	9.83
5	Nitragin (heavy)[a]	—	—	—	23	83	2.79	—	—	—
6	Standard	41	10	2.00	31	26	1.00	45	5	1.00
7	Standard (heavy)[a]	—	—	—	46	9	1.25	—	—	—
8	Urbana	59	56	12.00	40	25	1.80	40	100	14.15
9	Urbana (heavy)[a]	—	—	—	57	60	3.61	—	—	—
10	U. S. D. A	39	90	9.22	29	51	2.00	50	94	10.66
11	U. S. D. A. (heavy)[a]	—	—	—	—	—	—	—	—	—
12	Wisconsin (heavy)[a]	—	—	—	56	80	4.42	—	—	—
13	Soil (Craig Co., Okla.)	—	—	—	42	33	2.57	48	85	7.42
14	Soil (Craig Co., Okla.) (heavy)[a]	—	—	—	19	74	3.14	—	—	—
15	Soil Ames, Iowa	41	44	7.27	—	—	—	—	—	—
16	Soil Ames, Iowa (heavy)[a]	—	—	—	37	86	5.43	—	—	—

[a]Enough inoculating material to inoculate 1 bushel of seed placed in a row 1 rod long and mixed with soil.

The season was very dry after the soybeans were planted and the moisture content of the soil at time of planting seemed to be an important factor in nodule formation. In the same field in which the experiment on Yahola sandy loam was conducted, an area of Yahola clay loam was also present. All of the soybean inoculation studies crossed this soil type and, although a high percentage of plants were inoculated on the sandy soil, less than 10% of the soybean plants produced nodules in the heavier type of soil which was dry and in poor physical condition at time of planting.

Different investigators (5, 9, 11, 17) have shown that soil kept at a low moisture content throughout the growing season is unfavorable to nodule production, but the effect of the moisture content of the soil at planting time has not been emphasized in previous publications.

As a result of the previous field investigation an experiment was planned to study the effect of high and low moisture content of soils at time of planting on the formation of nodules on soybeans grown under controlled conditions. This experiment was conducted in the greenhouse, using Yahola sandy loam soil placed in 2-gallon galvanized iron cans. After the surface soil had dried out considerably, the different varieties of soybeans as given in Table 2 were planted. Three other varieties were included in the study but on account of poor germination the data secured from these varieties were omitted.

The soybean seeds were planted in soil containing about 8 to 10% moisture. The moisture content in the surface layer of soil probably varied, but it was high enough to allow germination to take place and there was sufficient water in the subsurface layers of soil to meet the needs of the young plants for a considerable period of time. One series of cans was watered immediately after the soybeans were planted, while the other series was not watered until 10 days later which was the same length of time that elapsed before the first rains occurred after the soybeans were planted in the Kirkland silt loam in the preceding experiment. The addition of water to this soil produced a hard crust on the surface and many of the plants in the first series were injured in forcing their way through this crust. Also, the seeds in the cans which were watered immediately germinated slower than the seeds planted in the soil containing a lower moisture content.

After the first 10-day period all of the cans were watered uniformly and were brought up to an optimum moisture content every two weeks. Equal volumes of water were added to each container except when the cans were weighed and little variation in the moisture

content of the soils occurred. The plants were removed from the soil 53 days after planting and the percentage of plants inoculated and the number of nodules on each inoculated plant were determined.

TABLE 2.—*The effect of soil moisture at time of planting on the inoculation of soybeans.*

No.	Variety	Moisture content	Number of plants studied	Inoculation %	Average number of nodules per plant
1	Biloxi	High	20	99.5	3.95
2		Low	36	80.5	3.66
3	Haberlandt	High	15	73.3	1.73
4		Low	12	58.4	1.86
5	Hollybrook	High	10	100.0	2.20
6		Low	24	66.6	1.81
7	Laredo	High	45	62.2	2.11
8		Low	41	63.4	2.66
9	Mammoth Yellow	High	17	82.3	4.22
10		Low	31	38.7	1.83
11	Morse	High	26	42.3	2.09
12		Low	36	44.4	1.75
13	Pine Dell Perfection	High	47	100.0	4.42
14		Low	31	82.6	2.28
15	Old Dominion	High	44	75.0	2.40
16		Low	57	50.9	2.34
17	Otootan	High	44	100.0	4.43
18		Low	31	99.3	4.50
19	Tarheel	High	30	100.0	8.00
20		Low	16	43.7	4.00
21	Virginia	High	33	78.8	2.31
22		Low	31	77.5	2.33
23	Wilson	High	36	94.4	3.52
24		Low	68	75.0	2.46
25	Wilson Early Black	High	39	64.1	1.60
26		Low	49	20.2	1.40

The source of the inoculating material used in this experiment was Nitragin which contained strains of organisms inoculating Wisconsin Black, Ito San, Manchu, Midwest, Peking, Mammoth Yellow, Black Eyebrow, and Hollybrook soybeans. It is quite evident that the moisture content at time of planting is an important factor in many instances if a maximum inoculation is to be secured. In 9 cases out of 13 a marked difference in the percentage of inoculated plants occurred when the soybeans were planted in a soil having a high moisture content as compared with a soil having a low moisture content. In the other four instances, the differences were not significant.* In the case of Morse soybeans considerably less than half

of the plants were inoculated which would indicate that this variety was not easily infected by the strains of organisms present in the culture used in this experiment. In 9 cases out of 13 more nodules were produced on the inoculated plants grown in soil having a high moisture content than those grown in a soil having a low moisture content. In the other four instances, there was very little difference between the number of nodules produced on plants which were grown in soils containing high and low moisture contents at time of planting.

How many more nodules one group of plants must have than another group in order for the difference to be significant was not determined in this investigation. Wilson (17) found that more than ± 12 nodules per 100 plants were probably significant in his experiment. There was a tendency for more primary nodules to develop in the soil with a high moisture content at time of planting, although this was not true in all cases.

Some of the varieties of soybeans tended to lift the seed coat out of the soil during germination, and at first it appeared that this might be correlated with poor nodule formation since the bacteria were on the seed coat at time of planting. Data secured on this point indicated, however, that many plants were well inoculated even though the seed coat was removed from the soil during the process of germination.

The data presented in Table 2 will probably help to explain why some farmers secure good inoculation and other farmers in adjacent fields secure relatively poor inoculation, although the same kind of bacteria were used to inoculate the seed. In a few instances, the low moisture content of the soil did not seem to influence appreciably the inoculation of the plants. In one instance, the percentage of inoculation was high, whether the soil was low or high in moisture content. In other instances, the percentages were rather low. In case of the high percentage of inoculation, the plants may have been particularly susceptible to the strains of bacteria in the culture. In the other cases most of the inoculation may have taken place after the first 10-day period when all containers were kept at the same moisture content.

Fred, Whiting, and Hastings (4) found that the legume bacteria soon die if allowed to dry on the seed; consequently, a third experiment was started to determine what effect planting soybeans in a perfectly dry soil would have on nodule formation, provided a culture was used which was capable of producing an abundance of nodules on a particular variety. Tarheel soybeans were used in this experiment.

They were inoculated with Nitragin culture and were planted in dry soil which did not contain enough moisture to produce germination. Water was added at different periods as given in Table 3. The maximum time which the seed remained in the dry soil was 12 days. It will be noted from a study of the data that the number of nodules per plant was nearly as large when the seed remained in dry soil for 12 days before water was added as the number of nodules produced on plants which were in the containers to which water was added as soon as the seeds were planted.

Moore (9) states that drought is not fatal to the bacteria and this experiment tends to support his statement, although it is entirely possible that a large number of the bacteria applied to the seed may die and yet good inoculation may be secured since only a few nodules are formed on each plant as compared with the numbers of bacteria which were originally on each seed. Apparently, when the plant roots are easily infected by the bacteria, good inoculation may be secured in unfavorable seasons even though the soybean seed is planted in dry soil. Most seed are not planted in soil which is too dry to prevent germination; consequently, the data presented in Table 2 are more nearly like those which would be secured under field conditions than in this experiment where the seed lay dormant until the water was applied to the soil. Under such conditions as good an

TABLE 3.—*The effect of additions of straw, fertilizer, tap water, and distilled water and depth of planting on the inoculation of Turheel soybeans.*

No.	Treatment	Soil moistened after planting	Number of plants studied	Average number of nodules per plant
1	Uninoculated	Immediately	51	0.00
2	Inoculated	Immediately	40	7.80
3	Inoculated	1 day later	34	8.00
4	Inoculated	2 days later	31	7.35
5	Inoculated	4 days later	44	7.15
6	Inoculated	8 days later	26	6.69
7	Inoculated	12 days later	17	6.94
8	2 tons of straw	Immediately	33	7.81
9	200 pounds 16% superphosphate (acid phosphate) and 50 pounds muriate of potash	Immediately	24	7.33
10	8 tons of manure	Immediately	25	6.96
11	Tap water added[a]	Immediately	20	4.25
12	Planted ½ inch deep	Immediately	26	10.23
13	Planted 1½ inch deep	Immediately	21	4.61

[a]Chlorinated water from city water supply.

opportunity for infection would occur as if the seed were originally planted in moist soil because the root-hairs did not develop until water was added to the soil, and at the same time the bacteria could begin to move about in the films of soil moisture and thus increase their opportunity for infection.

The effect of wheat straw, fertilizer, and tap water, which was chlorinated as it entered the city water supply, and depth of planting on inoculation was also studied in connection with the above experiment. The nodules on the soybeans grown in soil treated with wheat straw at the rate of 2 tons per acre were very large but were not any more numerous than on the roots of plants grown in untreated soil. Fertilization with mineral fertilizers or manure did not affect nodule formation in this soil. The addition of tap water to this soil depressed nodule formation nearly 50% as compared with plants grown in soil to which distilled water was added.

Soybean plants produced from seed planted 0.5 inch deep had over twice as many nodules per plant as soybean plants produced from seed planted 1½ inches deep. In both cases the plants began to appear on the same day. The only difference in the two depths of planting was that the 0.5-inch depth was in galvanized iron cans and the 1½-inch depth was in stoneware jars. The soil was not disturbed in any of the containers, and it is doubtful if the difference in the containers could cause this difference in inoculation.

In another experiment a field study was made on the formation of nodules on soybean plants which came from seed which was planted at different intervals after the seed were treated with soybean bacteria. Four different varieties of soybeans were inoculated on April 16 with culture secured from the United States Department of Agriculture and were planted at different points in Oklahoma as given in Table 4. All of these varieties were planted in moist soil and conditions were favorable for inoculation except at Carrier, Oklahoma, where the soybeans were planted on land which had previously been in alfalfa sod for several years. The best inoculation was secured when the soybeans were planted two days after the seed were inoculated. Although there was a variation in the soil type on which these experiments were conducted, the percentage of plants inoculated decreased as the number of days increased from the time the seed were inoculated to date of planting.

The results secured from the experiment at Carrier, Oklahoma, were rather peculiar. The soil in this field contained a considerable amount of nitrate nitrogen which seemed to influence the inoculation of Chiquita and Laredo soybeans more than it did the Old

Dominion and Virginia varieties. Since this plat was planted only nine days after the soybeans were inoculated, it is possible that the particular culture used was more specific for two of the varieties as might be suggested from the results secured at Purcell. Although a long period from the time the seed are inoculated until they are planted may result in the death of a large number of organisms, it is more likely that a decrease in vitality of the organisms which remain is responsible for lack of inoculation.

Scanlan (12) suggests the addition of calcium salts to the seed as a means of increasing the virility of the organisms. It has also been suggested that the reason why Danish farmers secure such good inoculation is because they use milk in transferring the bacteria to the soybean seed. Data are given in Table 5 comparing the use of milk and water as means of transferring bacteria to the soybean seed.

TABLE 4.—*The effect of delayed planting after seed treatment on the vitality of soybean bacteria as measured by successful inoculation and nodule production.*

			Chiquita			Laredo		
No.	Location	Date planted	Plants studied	Inoculated %	Nodules per plant	Plants studied	Inoculated %	Nodules per plant
1	Purcell, Okla.	Apr. 18	80	58.7	9.5	76	61.8	4.9
2	Sapulpa, Okla.	Apr. 27	39	28.2	8.6	77	54.5	5.5
3	Nowata, Okla.	May 2	38	39.4	5.1	46	54.3	3.0
4	Carrier, Okla.	Apr. 25	28	14.2	2.2	28	7.1	1.5
			Old Dominion			Virginia		
No.	Location	Date planted	Plants studied	Inoculated %	Nodules per plant	Plants studied	Inoculated %	Nodules per plant
1	Purcell, Okla.	Apr. 18	46	93.4	12.0	51	82.3	8.6
2	Sapulpa, Olka.	Apr. 27	58	56.8	5.2	31	35.4	3.2
3	Nowata, Okla.	May 2	44	25.0	3.5	38	28.9	2.0
4	Carrier, Okla.	Apr. 25	39	41.0	2.2	27	44.4	3.0

TABLE 5.—*The effect of milk and water suspensions of soybean bacteria on the inoculation of three varieties of soybeans.*

No.	Variety	Suspension used	Number of plants studied	Average number of nodules per plant
1	Otootan*	Milk	58	6.55
2	Otootan	Water	51	8.75
3	Tarheel	Milk	38	4.87
4	Tarheel	Water	32	5.65
5	Virginia	Milk	47	7.08
6	Virginia	Water	70	6.12

A Nitragin culture which had produced an abundance of nodules on several varieties of soybeans was used in this test.

In two instances a larger number of nodules were secured when water was used to transfer the bacteria to the seed than when the milk was used. In one case more nodules were produced on the plants which came from the seed treated with the milk suspension. Apparently, when conditions are favorable for infection from the standpoint of soil moisture and bacteria adapted to the plant, a milk suspension of bacteria has little advantage over a water suspension in increasing the formation of nodules. It is possible, however, that this soil contained a sufficient amount of available calcium and other salts which are present in milk and which may influence nodule formation so that a further addition of these materials had no effect.

TABLE 6.—*Variation in the inoculation of different varieties of soybeans grown under similar conditions and inoculated with the same kind of organisms.*

No.	Variety	Number of plants studied	Percentage of inoculation	Average number of nodules per plant
1	Biloxi	41	100.0	11 68
2	Chiquita	100	35.0	4.00
3	Haberlandt	42	95.2	9.73
4	Hollybrook	23	91.2	5.05
5	Laredo	125	48.0	4.00
6	Mammoth Yellow	45	86.3	9.26
7	Manchu	25	68.0	2.88
8	Midwest	33	94.0	10.20
9	Morse	15	66.6	3.50
10	Old Dominion	119	80.7	4.17
11	Otootan	86	87.3	10.15
12	Tarheel	51	70.6	8.50
13	Virginia (1)	77	40.3	2.45
14	Virginia (2)	92	50.0	2.37
15	Wilson	100	86.0	8.21
16	Wilson Early Black	106	72.7	6.82

The results of previous tests seemed to indicate a possibility that certain varieties of soybeans were more resistant to infection by a particular culture of soybean organism than other varieties. The very fact that some companies produce a culture composed of strains of organisms selected from different varieties of soybeans, while other companies produce a culture composed of a pure strain of soybean bacteria would indicate that there is some difference of opinion among people who are particularly interested in securing good inoculation. Two tests were made in connection with this experiment, one being conducted in the field and the other in the greenhouse.

The field test was started on two soil types and all varieties were planted in duplicate, but injury from jackrabbits prevented the securing of data except from one series. All of the soybean seed were inoculated with a mixed culture composed as follows: One-third from Nitragin, one-third from a U. S. Department of Agriculture culture, and one-third from a culture secured from the Urbana Laboratories at Urbana, Illinois. The soybeans were planted on April 25 and the young plants began to appear in five days. A good rain occurred 10 days after planting and the remainder of the season was favorable for growth. The soybean plants were removed from the soil on August 8, and the average number of nodules for each inoculated plant and the percentage of inoculation were determined for each variety. The results of this experiment are given in Table 6.

It is very evident from a study of these data that some varieties of soybeans either possess a marked resistance to infection or else the bacteria used were not especially adapted to the variety. There is also a fairly good correlation between the percentage of infection and the number of nodules per plant.

A similar experiment was conducted in the greenhouse during the winter of 1927 and 37 varieties of soybeans secured from W. J. Morse of the U. S. Department of Agriculture were studied. A pure culture isolated from the Tokio variety and secured from L. T. Leonard of the Bureau of Chemistry and Soils was compared with a pure culture isolated from the Manchu variety and furnished by I. L. Baldwin of the University of Wisconsin. The latter culture failed to produce any nodules on any of the varieties, but the culture furnished by Leonard produced good inoculation except in case of four varieties. The plants were harvested 64 days after planting and there was not only a considerable variation in the percentage of plants inoculated, but the number of nodules per plant was also quite variable. The data on this experiment are given in Table 7.

In a few cases, rather poor germination was secured, and where less than 20 plants were available for study, these cases were noted and should not be considered in any conclusion which might be drawn from the data presented. In no case did any variety completely resist infection, but the evidence seems to support the fact that one strain of soybean organisms is not capable of producing a maximum infection of all soybean varieties. In this particular instance the Chiquita, Columbia, Peking, and Lexington varieties seemed to be particularly resistant to the organism used. The Peking variety has been studied by Roberts and Erdman (1) and has been found rather difficult to inoculate with strains of organisms ordinarily present in commercial cultures.

TABLE 7.—*Results of an inoculation study on soybeans treated with a pure culture secured from nodules produced on the Tokio variety.*

No.	Variety	Percentage of inoculation	Average number of nodules per plant
1	Biloxi	100.0	3.0
2	Chestnut	85.7	1.7
3	Chiquita	46.1	2.1
4	Columbia	35.7	1.2
5	Dixie	85.0	3.4
6	Dunfield	100.0[a]	2.3
7	Easy Cook	90.0	4.0
8	Ebony	91.3	2.9
9	George Washington	100.0	5.6
10	Goshen Prolific	90.0	2.1
11	Haberlandt	87.5	3.1
12	Hahto	83.3	3.6
13	Hamilton	87.5	2.3
14	Herman	93.7	3.4
15	Hoosier	86.9	2.1
16	Illini	66.6[a]	2.5
17	Ilsoy	94.7	2.7
18	Laredo	90.4	2.3
19	Lexington	33.3	1.2
20	Mammoth Brown	85.7	5.1
21	Mammoth Yellow	57.1	2.2
22	Manchu	71.4[a]	2.4
23	Mandarin	81.7	2.2
24	Medium Green	75.0[a]	3.3
25	Merko	96.1	5.1
26	Minsoy	66.6[a]	3.0
27	Morse	100.0	4.0
28	Old Dominion	100.0	2.6
29	Peking	27.4	1.2
30	Southern Prolific	91.7	3.7
31	Soysota	100.0	3.4
32	Tarheel	70.0	3.5
33	Tokio	100.0[a]	1.0
34	Virginia	82.8	2.8
35	Wilson-Five	65.8	2.5
36	Wisconsin Black	89.4	2.0
37	Yokotenn	86.3	2.6
38	Mixture (uninoculated)	9.5	1.0

[a]Number of plants studied were too limited to make data of significance.

There has been considerable difference of opinion in regard to the symbiotic relationship which is supposed to exist between the soybean plant and the soybean bacteria. Many data have been published to show that inoculation of soybean plants has resulted in a large increase in the nitrogen content of the plant. However, in an

investigation made in this laboratory comparing heavily inoculated plants and other plants having an average number of nodules on their roots with uninoculated plants, it is quite evident that the inoculated plants are not always higher in total nitrogen. Considerable care was exercised in selecting these plants for analysis in order that accurate information could be secured. The degree of maturity, size of plant, and proportion of stems to leaves were all considered in selecting inoculated and uninoculated plants for comparison. The results of these analyses are given in Table 8.

TABLE 8.—*Studies on the nitrogen content of inoculated and uninoculated soybeans.*

No.	Variety	Where grown	Treatment	Percentage of nitrogen in plants
1	Chiquita	Nowata, Okla.	Inoculated	1.69
2	Chiquita	Nowata, Okla.	Uninoculated	2,21
3	Chiquita	Sapulpa, Okla.	Inoculated	1.74
4	Chiquita	Sapulpa, Okla.	Uninoculated	1.89
5	Chiquita	Stillwater, Okla.[a]	Inoculated	2.29
6	Chiquita	Stillwater, Okla.[a]	Uninoculated	2.32
7	Virginia	Glencoe, Okla.	Inoculated	1.86
8	Virginia	Glencoe, Okla.	Uninoculated	2.18
9	Virginia	Stillwater, Okla.	Inoculated	1.56[b]
10	Virginia	Stillwater, Okla.	Uninoculated	1.26[b]
11	Tarheel	Stillwater, Okla.[a]	Inoculated	2.76
12	Tarheel	Stillwater, Okla.[a]	Uninoculated	2.59
13	Tarheel	Stillwater, Okla.[a]	2 tons of straw per acre and inoculated	1.98
14	Tarheel	Stillwater, Okla.[a]	———	4.47 (nodules)

[a]Greenhouse plants.
[b]High percentage of stems.

Helz, et al, (7) have shown that there is a marked difference in the nitrogen-fixing power of certain strains of bacteria isolated from nodules secured from peas. It is no more than reasonable to expect that such a condition could occur in case of the soybean organisms which, as Wright (18) has demonstrated, can be divided into at at least two different types. In all probability these types could be divided into strains having variable capacities to fix atmospheric nitrogen when growing in the roots of plants. Another possibility that has been discussed by Waksman (16) is the absence of bacteriophage in the plants. Soybeans have never been grown on any of the soils used in this experiment and this might help to explain the results secured.

When 2 tons of wheat straw were applied to a soil before the soybeans were planted, a marked decrease in the nitrogen content of inoculated soybean plants occurred even though large vigorous

nodules were present on their roots. The plants growing in the soil treated with straw were just as large as plants growing in untreated soil which would indicate that a lack of minerals was not responsible for the lower nitrogen content of these plants. The nitrate nitrogen in the soil treated with straw was less than in the untreated soil, and apparently the fixation of nitrogen by the bacteria in the roots of plants grown on the soil treated with straw was not sufficient to make up for the larger amount of nitrogen absorbed by the soybean roots growing in the untreated soil.

SUMMARY

Various factors which affect the inoculation of soybeans were studied and the following results were secured.

Considerable difference exists in the ability of various cultures of soybean bacteria to produce nodules on soybean plants.

A low soil moisture content at time of planting may be an important factor in reducing nodule formation. This is probably due to the fact that the root-hairs on the main stem disappear before the bacteria have an opportunity to come in contact with them.

Keeping a soil at a high moisture content after it was held at a low moisture content for 10 days after soybeans were planted produced a lower percentage of inoculated plants and fewer nodules per plant in 9 out of 13 varieties of soybeans studied.

Preparing a milk suspension of soybean bacteria before adding the culture to the seed did not give any better inoculation than when a water suspension was used.

The addition of superphosphate (acid phosphate) and potash to the soil used in these experiments did not affect nodule formation.

The use of chlorinated water from the city water supply instead of distilled water to keep the soil at an optimum moisture content resulted in a considerable depression in nodule formation but did not completely prevent inoculation.

Field and greenhouse studies on the inoculation of a large number of soybean varieties, using both pure and mixed cultures, indicate that there is considerable variation in the ability of different varieties of soybeans to resist infection by a particular strain of soybean bacteria.

If the nitrogen content of plants can be used as a measure of the benefits derived from the association of soybean bacteria with the soybean plant, data are presented to show that under certain conditions uninoculated plants may contain a higher percentage of total nitrogen than inoculated plants. This would indicate that

some soybean bacteria may be of less value than others from the standpoint of nitrogen fixation and the subsequent utilization of this nitrogen by the soybean plant.

Well-inoculated soybean plants grown on soil treated with 2 tons of wheat straw per acre contained less nitrogen than inoculated plants grown on untreated soil. Various factors which might cause such a condition were considered.

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EFFECTS OF FERTILIZER TREATMENT ON THE FORMATION OF NODULES ON THE SOYBEAN[1]

G. E. HELZ AND A. L. WHITING[2]

In a study of the roots of leguminous plants under field conditions, cases were observed which indicated that fertilizers may have suppressed the normal formation of nodules. The contact of the fertilizers with the seed or its presence in too great a concentration near the seed apparently prevented nodule formation.

In crop rotations, inoculated legumes are often depended upon to supply in part the nitrogen for the other crops. There are certain legumes which are much benefited by fertilizer applications, especially on the soils deficient in potassium and phosphorus. If the roots are injured by any fertilizer, the effect of the natural or applied inoculation would be greatly reduced or entirely inhibited. The generally accepted results show that infection occurs through the root-hairs which, with injured roots, may be absent or too few to offer satisfactory chances for nodule formation. Certain constituents of fertilizers may increase soil acidity and thereby inhibit nodule formation. Others, used in a high concentration, cause a desiccation of the soil which would inhibit the action of the nodule bacteria. It is well known that certain salts decrease or totally inhibit the formation of root-hairs. Such a condition should decrease nodule formation and reduce the efficiency of the leguminous crop.

The literature dealing with the effects of fertilizers on seed germination, root development, and nodule formation is extensive. No attempt will be made to review it in detail. Truog[3] recently made a review of the literature bearing on germination and root development and has studied the problem experimentally with beans, peas, cowpeas, and soybeans, as well as many other plants. He, in common with other workers, has found the germination of leguminous seeds to be markedly retarded by fertilizer applications in direct contact with the seed. Application of the fertilizer above or below the seed largely eliminated the detrimental effect.

[1]Contribution from the Department of Agricultural Bacteriology, University of Wisconsin, Madison, Wis. Received for publication June 30, 1928.

[2]Formerly Assistant and Associate Professor, respectively.

[3]TRUOG, E., HARPER, H. J., MAGISTAD, O. C., PARKER, F. W., and SYKORA, J. Fertilizer experiments: Methods of application and effect on germination, early growth, hardiness, root growth, lodging, maturity, quality and yield. Wis. Agr. Exp. Sta. Res. Bul. 65. 1925.

Giöbel[4], from a careful study of the literature dealing with the effect of various fertilizers on nodule development, concludes, "Finally, the one outstanding conclusion that seems warranted to be drawn from this discussion and which the writer desires to strongly emphasize, is the fact that of all such factors considered as essential for optimum development of plants, soluble nitrogen in such form and quantities that it may be advantageously used by the plant for its vital processes, is the only one that exerts any detrimental effect upon nodule formation, and consequently on the process of fixation of nitrogen." However, much of the work on which the above statement was based did not bear directly with field practice. The results of his own work with alfalfa and soybeans indicate that small amounts of nitrate are effective in promoting seedling growth and nodule formation, while larger amounts adversely affect nodule formation.

EXPERIMENTAL

LABORATORY TESTS

The present work was planned to study the effects of fertilizer treatment under both field and laboratory conditions on the formation of nodules by soybeans.

The effect of moisture content and concentration of potassium chloride on the life of the nodule organism in soil.—Bottles containing 428 grams of dry soil were made up to moisture contents of 10, 25, and 40%. To bottles of each moisture content were added applications of potassium chloride equivalent to 200 pounds per acre. Other bottles with the above moisture contents were treated with applications equivalent to 400 pounds per acre. A number of bottles were not treated. The salt was spread over an area of about 3 square inches and covered with 0.5 inch of soil. The bottles were plugged with cotton and sterilized at 15 pounds pressure for nine hours. They were then planted with inoculated seeds. The bottles were weighed and the moisture content kept constant by the addition of sterile discilled water. The presence of the living nodule organism in the soil was determined after five days by applying a platinum loop to the seed and by transferring a bit of the surrounding soil to a mannitol agar slope.

The 200- and 400-pound treatments at all three moisture contents had killed the bacteria when they were placed directly in the salt. These results indicate that in the soil the nodule organisms will be totally killed or greatly diminished in numbers when brought in close proximity to a concentrated mass of potassium chloride.

[4]Giöbel, G. The relation of the soil nitrogen to nodule development and fixation of nitrogen by certain legumes. N. J. Agr. Exp. Sta. Bul. 436. 1926.

The effect of various concentrations of potassium chloride, ammonium sulfate, and monocalcium phosphate on the survival of the nodule organism in plant nutrient solution.—The concentrations were made in Bryan's solution to approximate those obtained by dissolving 200- and 400-pound per acre applications in the water of the upper 8 inches of soil at 10, 25, and 40% moisture contents. The solutions were placed in tubes and sterilized. They were then inoculated with a suspension of the soybean root-nodule bacteria. After 12 days incubation, transfers were made to mannitol agar slopes.

TABLE 1.—*The existence of the root nodule bacteria in various concentrations of salts after 12 days.*

Concentration of culture solution[a] equivalent to: Salt per acre in pounds	Moisture content %	Growth of transfers from culture solutions[b]: KCl	$CaH_4(PO_4)_2$	$(NH_4)_2SO_4$
200	10	++	—	++
	25	++	++	++
	40	++	++	++
400	10	++	—	++
	25	++	+	++
	40	++	+	++

[a]Bryan's solution used as the basic culture medium.
[b]++ =good growth, + =slight growth, — =no growth.

As recorded in Table 1, the monocalcium phosphate decreased the number or totally destroyed the organisms in the higher concentrations. This action was probably due to the acid nature of the salt used. Transfers from both the potassium chloride and the ammonium sulfate solutions gave good growth. Such salts, when totally dispersed in solutions equivalent to that of these soil moisture contents, had little injurious effect on the existence of the nodule organism. Any harmful effect on nodule production must therefore be caused by a physiological action on the plant or a concentration of the salt in a small portion of the soil moisture in the vicinity of the seed.

Greenhouse experiment on the effect of soil moisture content on nodule formation on soybeans.—The injurious effect of fertilizer treatment on nodule formation is greatest during a dry season. This effect may be due to the increased concentration of salts in the soil solution. In a soil where the moisture content is already low, the addition of certain salts would probably lower this further by drawing on the moisture content. In order to study the effect of moisture content on nodule

formation, wide-mouthed glass bottles containing 1 pound of dry soil were sterilized in an autoclave. After sterilization the series of bottles were made up to moisture contents of 10, 25, and 40%. Well-inoculated soybean seeds were placed in each bottle.

The nodule formation in the soil containing 40% moisture content was the best and was in every way typical of good nodulation. The soil containing 25% moisture also gave good nodule development. The 10% moisture content permitted fair growth of the plants but did not allow the formation of nodules. This behavior due to moisture content has often been observed in the field. In dry seasons a legume crop will often remain uninoculated until after the first rain.

The effect of different concentrations of certain fertilizer constituents on the growth and nodule formation of the soybean in solution culture.—Plants were grown in dark glass bottles containing 1 liter of solution inoculated with the soybean organism. The seeds were germinated between blotting paper and grown until the seedling root was about 1 inch long. They were then suspended from a cork in Crones' nutrient solution to which the potassium chloride was added. The normal healthy color of the roots in Crones' solution was a deep buff. In cases where the roots were white, the growth was not very vigorous. The white roots, although sometimes as extensive as the yellow ones, were thin and did not have a very rigid structure.

TABLE 2.—*Growth, root development, and nodule formation of soybeans in solution culture containing additional amounts of potassium chloride.*

Potassium chloride concentration equivalent to		Plant development	Root development	Average number of nodules per plant
Moisture content of soil %	Salt per acre in pounds			
	none	good	good	11
10	200	chlorotic	white, weak	13
10	400	chlorotic	weak, thin	7
25	200	good	good	19
25	400	chlorotic	good	8
40	200	good	good	23
40	400	good	good	19

With potassium chloride (Table 2) nodule formation was observed in all cases where root and plant development was normal. Whenever the salt concentration was great enough to cause abnormal growth or root development, the number of nodules was decreased.

In similar trials using ammonium sulfate and monocalcium phosphate, the plants made very poor growth in all concentrations of the salts and nodule formation was inhibited.

TABLE 3.—*Growth, root development, and nodule formation of soybeans in culture solutions containing dicyanodiamide.*

Concentration equivalent to pounds per acre[a]	Plant development	Root development	Nodule formation
10	good growth	short side roots	many nodules
25	fair growth	short side roots	many nodules
50	fair growth	short roots	several nodules
100	fair growth	thin, long roots	no nodules
200	fair growth	few thin, long roots	no nodules

[a]On the basis of a 15% moisture content of soil.

The polymerization to dicyanodiamide of cyanamid in soils has been shown to have a decided deleterious effect on the nitrifying organisms.[5] To study the effect of this salt on the nodule organism, plants were grown in solution cultures. Although the salt was toxic to the plants, it did not inhibit nodule formation when used in amounts which have been shown to be toxic to the nitrifying organisms. Greater amounts, however, did inhibit nodule formation (Table 3). These findings were checked up in field experiments where it was noticed that nodules formed even though the plants were injured.

FIELD EXPERIMENTS

The effect of mixed fertilizers on nodule formation.—In 1926, soybeans were planted on a Miami sandy loam with several fertilizer treatments. The mixed fertilizers used in this experiment were 0-8-4, 1-8-4, 2-8-4, 4-8-4, and 8-8-4.[6] The mixtures were made up with potassium chloride, monocalcium phosphate, and a form of fixed nitrogen (either cyanamid or the double salt of ammonium sulfate nitrate). Both 200- and 400-pound applications were made, the fertilizer being added with the seed in the row. Table 4 gives the results of this study.

The germination in this experiment decreased rapidly as the concentration of the salt increased. The plant growth with all of the treatments was uniform, no difference showing between any two treatments. The nodule formation, however, varied greatly. In a general way, the percentage of inoculated plants corresponded with the percentage of germination. The number of nodules per plant decreased rapidly as the concentration of the nitrogen portion of the fertilizer increased. The effect of the double salt of ammonium sulfate nitrate on nodule production was more noticeable than

[5]ALLISON, F. E. The effect of applications of cyanamid on the nitrate content of field soils. Jour. Agr. Res. 34:657–662. 1927.

[6]Formulas represent proportions of ammonia, phosphorus, and potassium.

TABLE 4.—*The effect of mixed fertilizers containing fixed nitrogen compounds on the nodule formation of soybeans in Miami sandy loam.*

Source of nitrogen	Formula of fertilizer	Percentage germination 200-pound treatment	Percentage germination 400-pound treatment	Percentage inoculated 200-pound treatment	Percentage inoculated 400-pound treatment
Cyanamid	0-8-4	77	55	91	60
	1-8-4	91	70	83	90
	2-8-4	61	33	32	19
	4-8-4	27	20	25	0
	8-8-4	25	21	26	0
	8-0-0	—	35	—	24
Ammonium sulfate nitrate (Luena saltpeter)	1-8-4	71	71	23	13
	2-8-4	57	43	6	0
	4-8-4	31	35	26	0
	8-8-4	47	27	8	0
	8-0-0	—	21	—	0

that of the cyanamid. The poor nodule formation may have been due to the presence of the nitrate and ammonia radicals in the compound which gave the plants a readily available source of nitrogen, or to a decrease in the number of root-hairs with which contact could be made by the nodule bacteria.

A similar experiment was conducted in 1927 in which the fertilizer was applied about 1 inch above and to one side of the seed. Various combinations of the three fertilizer elements were used in 150- and 300-pound applications and the nitrogen was supplied in four forms, *viz.*, cyanamid, ammonium sulfate, calcium nitrate, and sodium nitrate. Inoculated seed of Manchu soybeans was used. Growing conditions during the season were very good and all of the plants bore nodules. Nodule counts were made about the middle of the growing season (Table 5).

TABLE 5.—*Nodule formation of Manchu soybeans grown on Miami sandy loam with various fertilizer treatments.*

Fertilizer	Source of nitrogen	Average number of nodules per plant: No fertilizer	150 pounds fertilizer per acre	300 pounds fertilizer per acre
None	—	37.8	—	—
2-12-12	cyanamid	—	47.3	26.4
2-12-12	ammonium sulfate	—	29.2	29.4
Rock phosphate	—	—	58.8	46.7
Potassium chloride	—	—	55.3	25.3
Superphosphate (acid phosphate)	—	—	49.6	28.5
0-12-12	—	—	36.6	34.7
2-12-12	$Ca(NO_3)_2$	—	24.6	11.9
2-12-12	$NaNO_3$	—	18.4	20.9

Rock phosphate in both 150- and 300-pound applications appeared to stimulate nodule production. Potassium chloride, superphosphate (acid phosphate), and a 2-12-12 fertilizer with the nitrogen as cyanamid gave an increased nodulation with the 150-pound application. With the exception of the 150-pound application of 2-12-12 fertilizer containing cyanamid, all of the nitrogen applications decreased the formation of nodules. The 300-pound applications of potassium chloride and superphosphate (acid phosphate) decreased germination and also the number of nodules per plant.

SUMMARY

1. Applications of 200 and 400 pounds per acre of potassium chloride in soil of 10, 25, and 40% moisture content killed the nodule organisms on soybean seed when the seed was placed in intimate contact with the salt.

2. Soybean bacteria were not injured when placed in solutions equivalent to those obtained by the total dispersement of 200- and 400-pound per acre applications of potassium chloride or ammonium sulfate in the moisture of a soil containing 10, 25, or 40% water. In a similar experiment with monocalcium phosphate the bacteria were killed in the higher concentrations, probably due to the acid nature of the medium.

3. Normal nodulation of soybeans was secured in unfertilized soils of 25 and 40% moisture content. Poor nodulation resulted when the moisture content was reduced to 10%.

4. In solution cultures with various fertilizers normal nodulation was secured in every case in which the plant growth was not inhibited by the fertilizer.

5. In field trials, phosphorous and potassium fertilizers increased nodulation when used in amounts which were not inhibitory to germination.

6. Fertilizer applications in amounts large enough to lower the percentage of germination also decreased nodulation.

7. Applications of either ammonium or nitrate salts in the amounts used decreased nodule formation. Cyanamid in 150-pound per acre applications of a 2-12-12 fertilizer increased nodulation, while a 300-pound application of a similar fertilizer decreased nodule formation.

8. Dicyanodiamide is apparently less toxic to the nodule organism than to the soybean plant.

COMPARATIVE WINTERHARDINESS OF SPECIES AND VARIETIES OF VETCHES AND PEAS IN RELATION TO THEIR YIELDING ABILITY[1]

K. H. KLAGES[2]

One of the main factors determining the selection of species and varieties of leguminous winter annual forage plants is found in the comparative ability of these crops to endure winter conditions. Hairy vetch (*Vicia villosa*) is grown more extensively than any other vetch variety, due primarily to its high degree of winterhardiness. Some species of vetch, such as varieties of common vetch (*V. sativa*) and monantha vetch (*V. monantha*), have some very decided points of advantage over hairy vetch, yet the inability of these types to survive winter conditions constitutes in many localities the limiting factor to their production. Purple vetch (*V. atropurpurea*) is, according to McKee (2),[3] superior to other types in southern California due to "its ability to make more growth in a cool winter season and be ready to turn under at an earlier date in spring." Funchess (1) in Alabama was able to obtain larger yields and more pounds of nitrogen per acre with the use of monantha vetch at various dates of planting than with hairy vetch. The common vetches are generally considered to produce a more palatable hay than hairy vetch. In view of the above shortcomings of hairy vetch, it was deemed worth while to test the winterhardiness and yielding abilities of several species of vetches and peas.

The vetch and pea variety tests conducted at the Oklahoma Agricultural Experiment Station in the years 1926 to 1927 and 1927 to 1928 showed remarkable differences in the comparative winterhardiness of the different varieties of these crops.

1926-1927 TESTS

The varieties of vetches and peas listed in Table 1 were, with the exception of the plat of Austrian field peas, planted September 6, 1926. Seed of the Austrian field peas was not available till October

[1]Contribution from the Department of Agronomy, Oklahoma Agricultural and Mechanical College, Stillwater, Okla. Published with the approval of the Director of the Oklahoma Agricultural Experiment Station. Received for publication June 28, 1928.

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[3]Reference by number is to "Literature Cited," p. 987.

20. Good stands were obtained on all plats. Counts of surviving and dead plants were made during the end of February and percentages of winterkilling calculated.

Table 1 gives the degree of winterkilling expressed on a percentage basis, together with the yields of hay and seed of the surviving varieties. Two varieties of vetch, hairy and woolly-podded, and the Austrian field peas showed no winterkilling. The Hungarian vetch showed only a small percentage of killing. It will be noticed that the various strains of common vetch included in the test showed marked differences in winterhardiness. The hay yields of the respective varieties stand in direct relationship to their wintersurvival. It is reasonable to assume, and this assumption is substantiated by the 1927 to 1928 results, that the yields of the Austrian field peas were

TABLE 1.—*Degree of winterkilling and yields of species and varieties of vetches and peas for the cropping season, 1926 to 1927, at Stillwater, Oklahoma.*

Crop	Scientific name	Percentage of winter-killing	Yields: Hay in tons per acre	Yields: Seed in bushels per acre
1. Hairy vetch	*Vicia villosa*	0	3.30	11.0
2. Woolly-podded vetch	*V. dasycarpa*	0	2.82	10.8
3. Hungarian vetch	*V. pannonica*	4	1.65	13.8
4. Austrian field pea[a]	*Pisum sativum*	0	1.52	10.5
5. Common vetch (F. C. I. No. 02830)	*V. sativa*	11	1.49	10.0
6. Common vetch (Woods Seed Co.)	*V. sativa*	12	1.00	3.9
7. Common vetch (F. C. I. No. 32947)	*V. sativa*	12	0.83	4.5
8. Monantha vetch	*V. monantha*	35	0.50	0.4
9. Common vetch (F. C. I. No. 13430)	*V. sativa*	30	0.33	2.3
10. Noena vetch	*V. noena*	63	0.22	0.3
11. Common field peas	*P. sativum*	100	0	0
12. Common vetch (F. C. I. No. 18805)	*V. sativa*	100	0	0
13. Common vetch (F. C. I. No. 21582)	*V. sativa*	100	0	0
14. Pearl vetch	*V. sativa*	100	0	0
15. Large-podded vetch	*V. macrocarpa*	100	0	0
16. Bard vetch	*V. calcarta*	100	0	0
17. Bitter vetch	*V. ervilia*	100	0	0
18. Narrow-leaved vetch	*V. angustifolia*	100	0	0
19. Horse bean	*V. faba*	100	0	0
20. Tangier pea	*Lathyrus tingitanus*	100	0	0

[a]Planted October 20. All other varieties were planted September 6, 1926.

lowered due to their later date of seeding. On the other hand, the unavoidable delay in the planting of the Austrian field peas served to give further evidence of the winterhardiness of this crop.

Table 2 gives the temperature conditions for the winter months of 1926 to 1927 and 1927 to 1928. It will be noticed that the temperatures for December, January, and February for the first winter were above normal. The lowest temperature recorded during the first winter of the test was 5° F on January 5. The fact that volunteer oats lived through the winter of 1926 to 1927 without severe damage showed that temperatures were milder than normal.

TABLE 2.—*Temperature conditions during the winter months of 1926 to 1927 and 1927 to 1928.*

	Temperatures in degrees F.						
Month	Mean	Departure from normal	Highest	Date	Lowest	Date	Greatest daily range
			1926 to 1927				
September	71.8	—1.3	95	2	42	25	34
October	64.6	+3.7	89	11	35	25	45
November	46.3	—2.4	76	25	19	22	41
December	40.6	+1.8	73	3	6	15	48
January	37.9	+0.8	72	5	5	15	37
February	47.3	+9.9	77	16	11	10	39
			1927 to 1928				
September	73	—0.1	94	7	38	21	40
October	65	+4.1	89	26	39	13	42
November	53.7	+5.0	80	10	25	16	45
December	35.4	—3.5	66	6	−1	31	55
January	40.0	+3.3	75	14	0	1	41
February	43.6	+4.8	70	4	15	24	43

1927–1928 TESTS

Due to the mildness of the winter of 1926 to 1927, it was not considered worth while to continue work on those varieties of vetches and peas failing to survive the first year of the test. Consequently, only the 10 varieties coming through the first winter in part or without damage were planted in the fall of 1927. The date of planting was the same as in 1926, September 6. Good stands were obtained on all plats. Due to an abundance of fall rains, all varieties made a good growth through September, October, and November. Growth was checked with the coming of low temperatures towards the middle of December.

The degree of winterkilling and yields of the respective surviving varieties are given in Table 3.

TABLE 3.—*Degree of winterkilling and yields of species and varieties of vetches and peas for the cropping season 1927 to 1928 at Stillwater, Oklahoma.*

Crop	Scientific name	Percentage of winterkilling	Yields: Hay in tons per acre	Yields: Seed in bushels per acre
1. Hairy vetch	*V. villosa*	0	2.29	12.0
2. Woolly-podded vetch	*V. dasycarpa*	0	1.97	6.2
3. Hungarian vetch	*V. pannonica*	14	1.27	5.5
4. Austrian field pea	*P. sativum*	0	2.93	23.5
5. Common vetch (F. C. I. No. 02830)	*V. sativa*	100	0	0
6. Common vetch (Woods Seed Co.)	*V. sativa*	100	0	0
7. Common vetch (F. C. I. No. 32947)	*V. sativa*	100	0	0
8. Monantha vetch	*V. monantha*	100	0	0
9. Common vetch (F. C. I. No. 13430)	*V. sativa*	100	0	0
10. Noena vetch	*V. noena*	100	0	0

The winter of 1927 to 1928 was fairly severe. It was marked by dry cold winds towards the end of December and early in January. The temperature dropped down to —1°F on December 31 as compared to the minimum of 5°F of the previous winter (Table 2). The five varieties showing complete killing were severely damaged by dry cold winds during the middle of December and succumbed completely with the advent of zero temperatures towards the end of the month. The combined effects of low temperatures and dry winds led to a rapid desiccation of the plants of the non-hardy varieties. Two varieties of vetch, hairy and woolly-podded, and the Austrian field pea came through the winter with no damage, while the Hungarian vetch showed some winterkilling. The climatic conditions of the second winter were too severe to bring out any differences in the hardiness of the respective strains of common vetch included in the test as was the case in the winter of 1926 to 1927.

It will be noticed from Table 3 that the hay yields of the crops included in the test are again in direct relationship to their respective degrees of winterhardiness.

The test has not been carried out long enough so that the best crop of the four surviving the winter of 1927 to 1928, either for utilization for hay or green manure purposes, can be recommended. The line between winterhardy and non-hardy types has been found to be very distinct. The growing of those species and varieties of

vetches and peas showing complete killing in either season of the test is out of the question. The hazards involved in their production are too great.

Due to the relatively high percentage of winterkilling shown by the Hungarian vetch, the advisability of growing this crop in north central Oklahoma is questionable. According to McKee and Schoth (3), Hungarian vetch is well adapted to poorly drained lands. Since winter conditions in the eastern and southeastern parts of Oklahoma are not as severe as at Stillwater in the north central part of the state, Hungarian vetch may well be grown on poorly drained lands in those portions of the state.

Woolly-podded vetch is, according to Piper, et al (4), somewhat less winterhardy than hairy vetch. Climatic conditions during the two years of the test were not sufficiently severe to bring out any differences in the hardiness of these two species. The woolly-podded vetch and the Austrian field pea made more growth during late winter and early spring than the hairy vetch. It remains to be seen whether or not winters too severe for the survival of the woolly-podded vetch or the Austrian field pea may be encountered in north central Oklahoma.

SUMMARY

Of 20 species and varieties of vetches and peas grown at the Oklahoma Agricultural Experiment Station only two species of vetch, hairy (*Vicia villosa*) and woolly-podded (*V. dasycarpa*), and one variety of peas, the Austrian field pea (*Pisum sativum*), were found to survive winter conditions without showing a perceptible percentage of winterkilling.

Hungarian vetch (*V. pannonica*) showed a fair degree of winterhardiness.

The investigation has not progressed sufficiently to bring out differences in the degree of winterhardiness of hairy vetch, woolly-podded vetch, and the Austrian field pea.

The line between hardy and non-hardy species and varieties was, under the particular set of climatic conditions encountered during the winters of 1926 to 1927 and 1927 to 1928, very distinct. This was true especially during the second and more severe winter.

The yields of the species and varieties used in the test were found to be in direct relationship to their respective degrees of winterhardiness.

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THE FORMULA FOR INTERPRETING THE CORRELATION COEFFICIENT[1]

F. R. IMMER[2]

During the past two years, the formula $100\,(1 - \sqrt{1-R^2})$ has been used several times (2, p. 55; 1, 4, 6, 7)[3] as a means of measuring the proportion of total variability which may be accounted for by a given correlation coefficient. The error in the use of this formula, in the above sense, became apparent to the writer while preparing an article for publication (3). Later, W. B. Kemp, of the Maryland Agricultural Experiment Station, in a letter to H. K. Hayes, also pointed out the error in the way this formula has been used. The present note, correcting this error, was prepared at the suggestion of Dr. Hayes.

In the following discussion, extensive use is made of formulae given by Smith (8), Kelley (5), and Wright (9).

Let X = a dependent variable and A. B. C. —N a number of independent variables.

X' = an estimated value of X from a knowledge of the independent variables.

Z = $X - X'$, or the error in estimating X from a knowledge of A, B, C,—N.

Then σ_X = standard deviation of X.

$\sigma_{X'}$ = standard deviation of the estimated values of X.

σ_Z = standard deviation of the errors in estimating, usually called the standard error of estimate. This value is usually determined from the formula $\sigma_Z = \sigma_X\sqrt{1-R^2}$.

The term $\sqrt{1-R^2}$ (Kelley's coefficient of alienation), then, may be said to measure the failure to improve the estimate knowing the value of the correlation coefficient. The formula $100\,(1 - \sqrt{1-R^2})$ then expresses on a percentage basis the reduction in variability of the predicted values of the dependent variable as compared with the variability of the actual values taken about their mean.

It may be shown (8) that $\sigma^2_{X'} + \sigma^2_Z = \sigma^2_X$. By dividing through by σ^2_X we obtain:

$$\frac{\sigma^2_{X'}}{\sigma^2_X} + \frac{\sigma^2_Z}{\sigma^2_X} = 1.$$

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Published with the consent of the director as Journal Series Paper No. 792. Received for publication July 19, 1928.

[2]Instructor in Plant Genetics.

[3]Reference by number is to "Literature Cited," p. 989.

$\frac{\sigma^2_{X'}}{\sigma^2_X}$ may be said to measure the proportion of the total squared variability in the dependent variable that is due to the independent variables as expressed by X′. This is commonly known as a coefficient of determination.

$\frac{\sigma^2_Z}{\sigma^2_X}$ is the proportion of the total squared variability in the dependent variable not explained by the independent variables considered in calculating R.

Since $\frac{\sigma^2_{X'}}{\sigma^2_X} = R^2$ and $\frac{\sigma^2_Z}{\sigma^2_X} = K^2$ (where $K = \sqrt{1-R^2}$),

$R^2 + K^2 = 1$, and R^2 may be said to measure the proportion of the total squared variability in the dependent variable which may be explained in terms of its mathematical relations to the independent variables considered in the formula ($R_{X.ABC\ .\ N}$), leaving the proportion expressed by K^2 yet to be accounted for.

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NOTE

A FERTILIZER SPREADER FOR PLAT TREATMENT

A homemade hand-drawn fertilizer spreader has recently been designed by the writer (as shown in Fig. 1) and has been successfully used in applying fertilizer in an experimental way. Such a tool has been needed to secure more uniform distribution of fertilizers in experimental work, to lessen the disagreeable feature of making such application, and to avoid interference by wind.

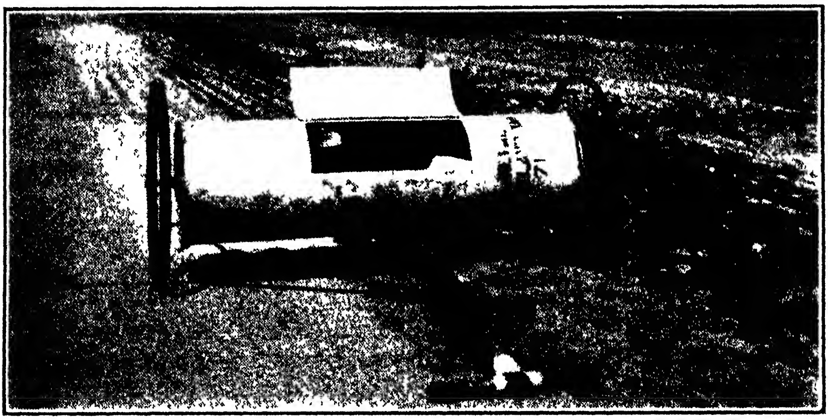

FIG. 1.

This sower is made by using 3/4 inch gas pipe for a shaft and old bicycle rims for wheels. The handle is from a lawn mower and can be detached along with one wheel, which is free to turn on the shaft, so that the tool can be placed in the rear of a run-about Ford for moving about in field fertilizer work. The hopper is made of a cylinder of 18-gage galvanized sheet metal. Feed holes are 1 inch in diameter and spaced 6 inches, while strips along either side carry a shutter with holes of the same dimension to adjust the rate of application as desired. Heavy wires passed through drill holes in the shaft carry brushes made from the inter-liner of an old automobile tire which serve as agitators for sweeping out the fertilizer drill box. Further improvements might be made by substituting metal wire brushes and by providing an opening that would extend the full length of the hopper to make easier access to the interior. This could be done by cutting out a segment or stip of the cylinder full length, which should be hinged, as shown in Fig. 1. A slat attached back of the hopper and carrying a hay-loader tooth to follow each feed hole should harrow dry material in sufficiently to prevent blowing about in the wind. The illustration shows the result of applying

10 pounds of fertilizer evenly to 1/20 acre of surface. The cost of materials for this fertilizer spreader was about $10.00.—W. L. Powers, *Chief in Soils, Oregon Agr. Exp. Station, Corvallis, Oregon.*

BOOK REVIEW

FIXATION OF ATMOSPHERIC NITROGEN

By F. A. Ernst. New York: D. Van Nostrand Company, Inc., 8 Warren St., VIII + 154 pp. illus. 1928. $2 50.

This book is a discussion in semi-technical language on the subject of commercial fixation of atmospheric nitrogen. Although in no sense a popular book, it is very readable and does not require much technical acquaintance with the subject discussed in order to understand it. It is of interest to the agronomist primarily because the author keeps in mind throughout the fertilizer value of the various forms of fixed nitrogen, and in discussing the importance of the subject, plainly has this object of the various processes primarily in mind.

The first chapter of the book discusses the importance of fixed nitrogen, both for fertilizers and for use in explosives, and shows the various sources from which it may be obtained. The second chapter takes up the history of commercial fixation of nitrogen and shows how it has been developed so extensively since the war as to become a rival of the Chilean nitrate industry.

The next three chapters take up, respectively, the three different processes of commercial fixation of nitrogen, namely, the arc process, the cyanamide process, and the direct synthetic ammonia process. The arc process is the oldest and involves the direct oxidation of nitrogen, which is brought about in an electric arc furnace. This process requires such a high expenditure of electrical energy as to be of little economic value. The cyanamide process requires less expenditure of energy and produces fixed nitrogen more cheaply. This process involves four steps, *viz.*, (1) production of lime from limestone; (2) the production of calcium carbide; (3) the production of gaseous nitrogen; and (4) the nitrification of carbide into calcium cyanamide. This process requires a large equipment and accordingly much capital investment. The direct ammonia process is the most recent development and is now tending to replace the earlier methods. This necessitates less expensive equipment and less expenditure of electrical energy. By this process nitrogen and hydrogen are combined to form ammonia in the presence of some catalyst such as iron oxide.

The sixth chapter discusses economic considerations and shows what possibilities there are of the synthetic nitrogen products, particularly those obtained from the last-mentioned process, competing successfully with Chilean nitrate. Chapter seven takes up the process by which the ammonia obtained from the direct ammonia process can be converted into fertilizers and other products of commercial value. The eighth chapter on "Statistics" discusses primarily the development of this industry in different parts of the world during recent years.

To the book are added several appendices giving various statistics concerning the cost of nitrogen and the amount manufactured in recent years by the various processes; also a bibliography of books and journal articles on the subject. (H. J. C.)

AGRONOMIC AFFAIRS

SUMMER MEETING OF CORN BELT SECTION

The Corn Belt Section of the American Society of Agronomy held its summer meeting in Ohio June 21 to 23, 1928.

The group assembled at Columbus, Thursday morning at 9.00, and heard a brief address of welcome by Dean Alfred Vivian of the College of Agriculture. Dr. Guy Conrey and Dr. J. B. Park described briefly the major soil and crop features of Ohio.

The first day was spent at Columbus looking over the crops and soils work on the farm of the Ohio State University. Late in the afternoon the group drove to Wooster.

All day Friday and Saturday morning were spent on the agronomy plats of the Ohio Agricultural Experiment Station. The banquet Friday evening at the Wooster Country Club was featured by Dean Vivian's lecture on Beautiful Ohio in which he showed colored slides from photographs of rural beauty spots in Ohio.

An invitation from Professor R. I. Throckmorton to meet in Kansas next year was accepted with enthusiasm.

Fifty persons attended the meeting, representing the following states: Kansas, Iowa, Wisconsin, Michigan, Illinois, Indiana, and Ohio. Representatives of the U. S. Department of Agriculture and of several fertilizer companies also were present.

CONFERENCE OF EXTENSION AGRONOMISTS

A conference of extension agronomists was held at Manhattan, Kansas, June 11 and 12, and was attended by representatives from Iowa, Missouri, Oklahoma, New Mexico, Colorado, Nebraska, and Kansas.

The first day of the conference was devoted to a study of the agronomic experimental plats at Manhattan and the second day to a discussion of agronomic extension work in the states represented. O. S. Fisher, Extension Agronomist, U. S. Department of Agriculture, who presided, appointed a committee consisting of Waldo Kidder, Colorado, *chairman*, and a member from each of the other states represented, to prepare a plan for coordinating more effectively the work in regions of similar natural conditions.

ANNUAL MEETING OF THE SOCIETY

President A. G. McCall has issued a preliminary announcement of the annual meeting of the Society to be held at the New Willard Hotel, Washington, D. C., November 22 and 23. One afternoon session is to be devoted to contributed papers, and with reference to this part of the program President McCall makes the following statement:

"In the preparation of the program for the November meeting of the American Society of Agronomy one session is to be devoted to submitted papers. The titles of the papers which members may wish to present should be in the hands of the Secretary, Dr. P. E. Brown, Ames, Iowa, not later than October 10. Since it is expected that a large number of papers will be submitted, it is suggested that authors be prepared to present the salient features within a 10 or 12 minute period. When titles are submitted members should indicate the amount of time which they will require, not to exceed 15 minutes."

Symposia topics and leaders will include "Soil Organic Matter and Green Manuring," J. G. Lipman; "Soil Erosion," H. H. Bennett; "Tobacco Research," W. L. Slate; and "Application of Base Exchange Methods," F. W. Parker. An Extension Section program will be led by O. S. Fisher.

THE MEXICAN AGROLOGICAL SOCIETY

The Mexican Agrological Society was organized at a meeting in Meoqui, Mexico, on July 12, 1928, with W. E. Packard, *President;* C. F. Shaw, *Honorary Vice-President;* Professor A. Brambila, *Secretary,* and an Executive Committee composed of these officers and Dr. L. Fourton, M. Y. Solorzano, and A. E. Kocher.

The membership consists of the scientific staff of the Agronomy Department of the Comision Nacional de Irrigacion, the staff of the Mexican Department of Agriculture, most of the staff of the National College of Agriculture at Chapingo, several agricultural county agents, and a number of others connected with investigation, teaching, or research in agriculture.

The aim of the Society is to promote research along the lines of soils, agronomy, and related fields; to afford better means for intercourse and exchange of views between those who are working in these fields; and to keep a closer contact between these men and the scientists in other parts of the world.

The address of the President is Casa del Lago, Chapultepec, D. F., Mexico, and that of the Secretary is Division de Quimica y Suelos, Direccion General de Agricultura, San Jacinto, D. F., Mexico.

The meeting at which the Society was organized was a conference of all of the men working in soils and agronomy in Mexico. This continued for a period of one month with courses of lectures on soil formation, soil classification, and soil physics by Professor C. F. Shaw of the University of California, together with several lectures and discussions on irrigation and land settlement by W. E. Packard of the Comision Nacional de Irrigacion, on soil survey methods by A. E. Kocher of the same organization, on soil chemistry by Professor Fourton of the National College of Agriculture and Professor Brambila of the Mexican Department of Agriculture and by other members of the conference. The lectures and discussions were supplemented by field excursions into the desert and to the irrigated sections of the region, where soil conditions are complex and show some very interesting developments.

NEWS ITEMS

E. B. Early, a 1928 graduate of the South Carolina A. and M. College (Clemson), was on August 1 appointed Fellow in Agronomy in the Virginia Polytechnic Institute, Blacksburg, Va.

Dr. C. F. Hottes, Professor of Plant Physiology, University of Illinois, and Consulting Plant Physiologist for the Agronomy Department, has been appointed Head of the Botany Department, to succeed Dr. H. L. Shantz, who has resigned to become President of the University of Arizona, Tucson, Arizona.

O. A. Pope, Instructor in Field Crops, Delaware Agricultural Experiment Station, has accepted a graduate assistantship in plant breeding at Iowa State College.

H. C. Harris has been appointed Assistant Professor of Agronomy at the Delaware Experiment Station. Dr. Harris is a graduate of North Carolina University and received his Ph.D. from Cornell University. He will take the place of Professor Runk, resigned.

G. L. Schuster, Head of the Agronomy Department, Delaware Agricultural Experiment Station, has returned to his duties after a year's leave of absence for study at Cornell.

H. E. Hammar has been granted a year's leave of absence from the Everglades Experiment Station, Belle Glade, Florida, for graduate work in soils at Rutgers College.

R. S. Shaw, Dean and Director of the Agricultural Division and Experiment Station of Michigan State College since 1908, was appointed President of Michigan State College on May 22, replacing President K. L. Butterfield, resigned.

J. F. Cox, Head of the Farm Crops Department, Michigan State College since 1917, was appointed Dean of Agriculture June 15.

V. R. Gardner, Head of the Horticultural Department, Michigan State College, was appointed Director of the Experiment Station June 15, retaining the Headship of the Horticultural Department

H. C. Rather, Extension Leader in Farm Crops at Michigan State College, was appointed Professor of Farm Crops and Head of the Experiment Station Section of Farm Crops, June 15.

A. J. Ogaard, formerly Extension Agronomist at Montana State College and recently engaged in educational work for the National Pure Seed Association, died suddenly in a hotel in Salt Lake City on Sunday, August 26.

G. I. Christie, formerly Director and Extension Director of the Indiana Agricultural Experiment Station has accepted the Presidency of Guelph Agricultural College. Prof. J. H Skinner, Dean of the College of Agriculture, has been made Director of the Experiment Station.

C. T. Dowell, Dean of the College of Agriculture and Director of the Experiment Station at the Oklahoma Agricultural and Mechanical College, has left the Oklahoma institution and is now Dean of Agriculture and Director of the Louisiana Experiment Station at Baton Rouge.

Fred Griffee has resigned as Professor of Plant Breeding at the Oklahoma Agricultural and Mechanical College to accept a position in the Department of Biology at the University of Maine. Dr. Griffee succeeds Dr. Karl Sax who has accepted an appointment at Harvard University.

Charles N. Ageton, consulting chemist with laboratories in Havana, Cuba, and who had an extensive practice among the sugar producers of the island, was killed in an aeroplane accident on August 15 while flying from Havana to Key West.

R. E. Decker, formerly county agricultural agent in Jackson County, Michigan, has been appointed Extension Specialist in Crops at Michigan State College.

Nelson McKaig, jr., following completion of postgraduate studies at the University of Chicago for the degree of doctor of philosophy, has been appointed associate soil technologist in the Bureau of Chemistry and Soils and assigned to research studies on soil fertility problems with sugar cane in the South. His present headquarters is at the United States sugar plant field station, Houma, La.

A NEWS dispatch under a Philadelphia date line of August 21, 1928, contains the following information:

"Adco, Ltd., the company which controls the patents for making manure synthetically from straw, corn stalks and garden refuse without the intervention of animals, has brought suit in the Federal courts against Mr. E. M. Poirot, of the Poirot Farms, Golden City, Mo. The company alleges that Mr. Poirot used without authority the formula for a reagent covered by one of its early patents. Under the law, any such use, even in small lots for personal employment, constitutes an infringement and renders the user liable to prosecution."

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RECENT DEVELOPMENTS IN ENTOMOLOGICAL RESEARCH ON THE CORN BORER[1]

D. J. CAFFREY[2]

When the European corn borer (*Pyrausta nubilalis* Hubn.) was discovered in the United States during the summer of 1917, it was recognized that American agriculture was confronted with a new and important plant pest, concerning which little of a biological nature was known in the Old World. Consequently, Vinal (1)[3] of the Massachusetts Experiment Station, who detected the presence of the corn borer in this country, promptly instituted investigations to determine the gross facts concerning the biology of the insect and the most promising methods for its control.

These investigations were continued in Massachusetts during 1918 in cooperation with the U. S. Bureau of Entomology (2). The natural spread of the corn borer soon involved additional states in New England. Also, as a result of separate introductions into New York and Ontario, Canada, it spread to include portions of the Great Lakes States. This dispersion was accompanied by the establishment of federal and state research activities in all of the important areas affected. Recognizing that fundamental information regarding the corn borer in Europe was essential for the conduct of an intelligent research program looking toward the control of the insect in America, entomological and ecological investigations were begun in Europe during 1919 and have been supplemented from time to time by additional resources and personnel.

[1]Contribution from the Bureau of Entomology, U. S. Dept. of Agriculture, Washington, D. C. Paper read before the joint meeting of the Society and Section O of the American Association for the Advancement of Science at Nashville, Tenn., Dec. 27, 1927.

[2]Entomologist, Cereal and Forage Insects.

[3]Reference by number is to "Literature Cited," p. 1010.

At the present time the corn borer research activities of the U. S. Bureau of Entomology are centered at the following laboratories and stations: Arlington, Mass.; Silver Creek, N. Y.; Sandusky and Toledo, Ohio; Monroe, Mich.; Hyeres, France; and Budapest, Hungary.

An analysis of the information secured by the entomologists during the early years of their research indicated that mechanical measures, cultural practices, and other agronomic adaptations in the culture of corn would probably constitute the chief mode of procedure in the solution of the corn borer problem. This development rendered necessary the assistance of specialists in other lines of endeavor, particularly agricultural engineers, agronomists, soil specialists, chemists, economists, and allied workers, whose function it became to apply the fundamental knowledge concerning the behavior of the insect obtained by the entomologists.

With a background of 10 years of corn borer entomological research it seems desirable to consider briefly the principal phases studied and to emphasize the more recent developments.

GENERAL BIOLOGY

Since many questions relating to control were involved in the biology of the insect, this phase of research was among the first to receive critical attention.

SEASONAL OCCURRENCE AND LIFE HISTORY

Field and laboratory studies of several years duration have shown that the corn borer, as in the instance of other insects, reacts quite directly to the influence of climate, with special reference to conditions of temperature and moisture. This applies to the seasonal occurrence as well as to the duration of each stage of the insect, which varies each year, within certain restricted limits, in accordance with the prevailing climatic conditions.

Originally it was proposed that the existing variation in the number of generations annually might be attributed to the presence of two distinct biological species. Research studies wherein individuals of both sexes from both groups were crossbred demonstrated that all such crosses produced fertile eggs and that the resulting progeny, after several generations, exhibited a pronounced tendency to develop two generations.

The presence of two geographic races was another theory advanced as a possible explanation of the variation in seasonal cycles. In investigating this conjecture two-generation material was transferred to a one-generation locality and reared for a succession of generations

in large field cages, while one-generation material was transferred to a two-generation locality and reared under similar conditions. These transfer experiments have now proceeded for eight seasons and in each instance the material has adhered to the seasonal cycle of its original habitat. While the possible presence of two geographic races has not been definitely shown, or disproved, it is realized that the duration of the experiment has not been sufficient to ascertain whether environment will eventually induce a change in seasonal cycle. A study of possible symbiotic interference with the seasonal cycle of the corn borer in various environments, a theory advanced by Pospielov in explanation of the variation in the season cycle of the sugar-beet webworm in Russia, indicated that this influence was not apparent in the instance of the corn borer.

In an attempt to analyze and evaluate the influence of temperature and mositure upon the life economy of the borer, Babcock conducted a series of studies under controlled conditions (3) which demonstrated that fluctuation of temperature exerted an important influence upon the duration and occurrence of the different stages, particularly at temperatures 10° to 15° F above the actual threshold of development, and that the seasonal distribution of moisture (precipitation, humidity, and evaporation) was of great importance. Applied to field conditions within the infested areas, Babcock's results indicated that during the spring months the daily temperatures are, for a greater part of the time, within the more influential limits to accelerate the development of the corn borer, and that the seasonal distribution of precipitation was of critical importance in influencing the seasonal cycle and abundance of the insect, with particular reference to the requirement of contact moisture by the overwintering larvae just prior to pupation. In fact an analysis of available meteorological records throughout the known world distribution of the corn borer, in connection with the facts developed by Babcock, indicated that, within certain temperature limits, the number of generations occurring annually was greatly influenced by the annual distribution of precipitation, particularly during the critical winter and early spring months. In areas where abundant precipitation occurred during the winter and early spring months, a two-generation seasonal cycle developed. In areas where the reverse was true, only a single generation developed.

The influence of light upon the habits and development of the corn borer is now being studied, but no definite results are available at this time.

ADULT HABITS

Flight.—Since preliminary observations indicated that natural dispersion occurred to a great extent by flight of the adults, detailed research studies on adult flight were emphasized. These studies (3) resulted in the recovery of stained adults of both sexes five miles from the point of liberation on land and 20 miles from the point of liberation on water. Moreover, it was determined that the adults were able to alight upon the surface of the water and again take flight. Flight usually occurred in the direction of the prevailing wind, although exceptions to this have been observed in the instance of light breezes. The moths are essentially nocturnal in habit and are most active between dusk and late evening. Hills, wooded areas, bodies of water, and similar natural features did not prove barriers to the flight of the moths.

Oviposition.—Detailed studies have shown that eggs are deposited in greatest numbers during the period from dusk until late evening. Oviposition usually occurs on the underside of the leaves of the host plant, although eggs are found infrequently upon the upper sides of the leaves. Special research to determine climatic influences upon oviposition demonstrated that nocturnal temperatures above 66° to 68° F, with relative humidity slightly above the normal, created optimum conditions for maximum oviposition and flight, whereas temperatures lower than this, accompanied by sub-normal humidity, had a retarding influence upon oviposition and flight.

Under cage conditions long-continued experiments showed each female depositing from approximately 250 to 500 eggs, with an average of 400 eggs per female and a maximum of over 1,900 eggs in a series of clusters over a period ranging from 10 to 24 days. Confinement observations showed that a single mating was sufficient to fertilize the total complement of eggs and that each male would fertilize several females.

Corn proved to be the favorite host for oviposition, although under two-generation conditions in New England several of the common vegetables, flowers, and weeds served commonly as hosts.

Tropisms.—Studies to determine the tropic responses of the moths demonstrated that they were not attracted in any numbers to lights of different types, colors, or intensities. This included experiments with lights originating from electricity, acetylene, gasoline, and kerosene, when used alone or in combination with various attrahents and when moving or stationary. Less than 1% of the total moths in the vicinity were captured in any single experiment.

Negative results were secured in attempting to attract the moths to various substances ordinarily effective in attracting lepidopterous adults. This included the various aromatic oils, fresh or decaying fruit pulp and juices, various sirups, etc. This activity has resulted recently in a cooperative project between the U. S. Bureau of Entomology and the Boyce Thompson Institute of Plant Research involving an extensive inquiry into the chemotropic and phototropic responses of the borer, together with related studies upon the physiology and biochemistry of the corn plant and the corn borer. This investigation has for its principal objective the determination and isolation of the fundamental attrahent which induces the corn borer to select the corn plant as its principal host, with the hope that success in this effort may lead to its obvious economic application.

The phenomenon of assembling, or sexual attraction, does not appear to be as pronounced in the corn borer as that exhibited by many other Lepidoptera, since only occasional males were attracted at any hour during the day or night to cages containing virgin females.

LARVAL HABITS

The habits of the larvae, from the time they hatch from the egg until pupation, have been carefully studied. Nearly 100% of the eggs are fertile and hatch under normal conditions. Exposure to direct sunlight, or total submergence in water for periods exceeding six to seven hours, prevented the hatching of fertile eggs. Likewise, the burial of eggs in soil to a depth of 4 inches or more, prevented the newly hatched larvae from reaching the soil surface.

Feeding habits.—The first meal of the newly hatched larvae is usually upon the egg shell. They soon begin to feed upon the exterior of the plant, however, and from this time until reaching maturity the larvae feed or bore in or upon all parts of the corn plant except the fibrous roots. Detailed studies of larval feeding habits have shown that the larvae prefer as food the portions of the plant which are most succulent and rich in sugar. The harder and less nutritious portions of the plant are merely bored out and cast aside. After reaching maturity no real feeding occurs, although the larvae may continue their boring activities in search of suitable hibernating or pupation quarters. In the instance of hibernating larvae structural changes in the internal tract as a phase of hibernation prevent any feeding by the larvae in the spring.

Larval establishment and survival.—In view of the fecundity of the *P. nubilalis* female and the relatively small number of larvae reaching maturity as compared to the eggs deposited in any given field, it was apparent that a high mortality from natural causes excluding para-

sitism prevailed among the young larvae. Investigations by Patch (3), Bartley, and others disclosed that only about 15% on an average of the larvae hatching reached maturity. The causes for this mortality were manifold but could be attributed for the most part to heavy rains, high winds, desiccation, and starvation. In general, the percentage of survival in late-planted corn was lower than in earlier-planted corn, but this general consideration was subject to important variation.

Distribution of larvae in the plant.—While the host plant is green and succulent, it may be entered and fed upon or tunnelled by the feeding larvae at practically any point, but as the plant nears maturity and begins to dry out in its upper portions, the larvae exhibit a tendency to migrate to the lower and more succulent portions. Field research has shown in general that from cornstalks cut during the middle of September approximaaely 7% of the original borer population remain in 6-inch stubble, 17% in 12-inch stubble, 20% in 15-inch stubble, and 23% in 18-inch stubble, while 1% or less remain in 2-inch stubble. Cornstalks cut during early November showed about three times as many borers in stubble of any given height as in stubble from cornstalks cut during mid-September. With this evidence it became apparent that when farming practice included the cutting of corn, it should be cut as low and as early as possible.

Larval migration.—Since the migration of larvae exerted an important influence upon many phases of control, this point has been given intensive consideration. Field studies in growing corn showed the larvae to be capable of migration to a maximum distance of 15 feet in its natural environment. Locomotion studies under controlled conditions developed the fact that larvae from the third to sixth instars could, under compulsion, travel for distances exceeding 100 feet, a circumstance which apparently never develops under natural conditions.

As a portion of the studies to determine the effectiveness of plowing as a control measure, it was found (8) that under one-generation conditions the majority of the larvae contained in infested material plowed under in the late summer, early autumn, or spring, when the soil temperature at a depth of 6 inches was above approximately 45° to 50° F, migrated to the soil surface within a few days, whereas larvae treated in a similar manner during the late fall, when the soil temperature was below these limits, remained below the soil surface throughout the winter and early spring until the soil temperature reached approximately 45° to 50°F, at which time they migrated to the soil surface.

Continuing these studies, evidence was secured that in a cleanly plowed field less than 1% of the borers reaching the soil surface were able to migrate to a distance of 30 feet and 5% of the individuals migrated for a distance of 25 feet. In areas where the soil surface was practically free of all plant debris, an average of from less than 1 to 2% of the plowed-down borers were able to find adequate shelter and complete their development to the adult stage.

In the presence of severe infestation, or when infested plants collapse, or when for any reason they become unsuitable for food or shelter during the period of larval activity, local migration is a common occurrence. Under these circumstances many types and species of plants are entered by the larvae for shelter, even when such plants do not function as food. This phenomenon results frequently in corn borer larvae being found in inanimate objects, such as fences, poles, under the rough bark of trees, etc.

Much of the larval migration occurs at night, an apparent adaptation by the larvae to escape their natural enemies

HIBERNATION

The corn borer normally passes the winter as a full-grown larva within the tunnel made in its host plant during the previous summer and fall. Dissections of the larvae during hibernation reveal that the vital organs are surrounded by fatty tissue which apparently aids them not only in surviving the adverse conditions to which they are exposed, but also supplies available means for carrying on the metabolism which occurs during this period.

The normal percentage of winter mortality over the 10-year period under observation has been very low, seldom exceeding 10%, and judging from data secured in America and in Europe there does not appear to be any climatic limitation to the distribution or multiplication of the borer which depends upon winter mortality.

At this period in their development the larvae have been shown to be exceedingly resistant to external influences. Many of them are able to survive submergence in water for an observed period as long as 43 days, a circumstance which contributes greatly to the natural dispersion of the species through the water-drift of infested material, and to survive the insecticidal fumigants now in use, including hydrocyanic-acid gas at atmospheric pressures and under partial (25-inch) vacuum. This observed resistance was made the subject of special research by Crowell (4) who showed that corn borer larvae are equipped with an exceptionally effective tracheal-closing apparatus. In a series of experiments dealing with the hibernation period,

Babcock (5) found that contact moisture at this period was of extreme importance in affecting future seasonal development and was essential for the normal completion of histolysis, the effect of depriving hibernating larvae of normal precipitation being directly dependent upon the amount of contact moisture received and the temperature. Applied to practical conditions, further research has shown that cornstalks stored under ordinary farm conditions are an important source of re-infestation.

SPREAD

From what has been stated, it is apparent that natural spread of the corn borer may occur principally through flight of the adults or by the water-drift of infested material. The water-drift phase has attracted increased attention as a result of recent experiments which resulted in the recovery of tagged non-infested cornstalks along river courses at distances exceeding 200 miles from the point of origin.

The phase of artificial spread through carriage of infested plants, or plant products, has been made the subject of continued research. Results from these studies were used as a basis for present quarantine restrictions governing the movement of susceptible materials out of infested areas.

HOST PLANTS

Host plant research has shown that corn appears to be the preferred host of the European corn borer throughout its distribution in the Old World and in the New. It is apparently an adopted host since the corn borer is accepted as indigenous to Europe or Asia and corn is generally accepted as originating in America. The original host of the corn borer has been made the subject of general research as a result of which it has been advanced by Jablonowski (6), Babcock (3), and others that the original host was either the hop plant or some of the larger European or Asiatic grasses or grasslike plants. This point, however, is still a matter of conjecture. Hops, millet, hemp, and broom corn are common hosts in the Old World.

In the one-generation areas of its occurrence in America the corn borer is confined almost exclusively to corn as a direct food plant, although in the presence of medium or severe infestation it has been found feeding infrequently in a few other plants and utilizing still others as shelter plants. In the Great Lakes district a total of 46 species of plants (principally large succulent weeds) have been found infested, while in New England a total of 224 species have been recorded as hosts (3). This latter has included, in addition to corn, many of the common vegetables, field crops, flowers, and weeds.

EXTENT OF INJURY AND ECONOMIC LOSS

The status of *P. nubilalis* as a serious pest of corn, hops, millet, and hemp has long been recognized in the Old World, according to existing records since 1835. Babcock's field studies (3) during the period of 1924 to 1927 have revealed average losses to the corn crop ranging from 5 to 25%, with maximums of 100%, in different districts of the corn-growing regions of Hungary, Yugoslavia, and Rumania.

In America the corn borer has caused serious losses to sweet and field corn and to vegetables in New England. During the peak of the infestation in that section in 1922, average estimated losess ranged from 5 to 20%, and approached a maximum of 100% in the more heavily infested districts.

In the one-generation areas of the Great Lakes area of the United States no widespread economic losses have developed to date, although the estimated losses in certain corn fields located in a limited district of the older portion of the area have exceeded 25%. In the Province of Ontario extensive losses, approaching 100% in many instances, have developed in typical dent corn fields over an area of approximately 1,200 square miles. This has resulted in greatly reduced acreages devoted to corn and radical changes in farm practice.

Special research studies have shown that the major crop loss to corn is caused by the feeding of the larvae in the stalks and ear-stems, although the direct injury to the ears has been of great importance and has led, in many instances, to a secondary source of injury induced by the entrance of various fungi and plant diseases through the perforations in the husks made by the larvae when entering or leaving the ears.

DISTRIBUTION

The records of foreign authors, together with additional field explorations by American entomologists, have revealed that *P. nubilalis* is widely distributed in central and southern Europe, Russia, Asia Minor, India, China, Siberia, Korea, Japan, the Philippines, and Guam. The species is present within a wide geographic range in the Northern Hemisphere, extending from latitude 58° north (Livonia) to 13° north (Guam and the Philippines). Its climatic range embraces a very wide contrast, varying from the dry steppes of southeastern Russia (Tsaritsyn), where the annual mean temperature averages 44.6°F and the precipitation 13.11 inches annually, to the warm equable temperatures of Guam featured by an average annual mean of 81.7°F and a mean precipitation of 97.27 inches. Judging from this adaptability to a wide range of climatic conditions exhibited by the species, it appears there would be no climatic barrier to prevent

it from ultimately becoming established over the greater part of the arable regions of the United States wherever its host plants are grown.

NATURAL ENEMIES

Although a variety of natural enemies of the corn borer have been recorded, usually they do not attack the insect in any appreciable numbers and cannot from present indications be relied upon to hold the pest in check.

Since native insect parasites were destroying on an average less than 1% of the total borer population, as reported by Jones (3), research studies were begun in Europe by Thompson in 1919 to determine the presence and economic status of parasites in the native home of the insect. This research resulted in establishing the presence of 12 species of parasites which seemed suitable for introduction to the United States. After sufficient research to determine that none of these species could become injurious or enter into detrimental conflict, a total of nearly 400,000 individuals were imported. A portion of these were liberated directly in infested corn fields by Jones and Caffrey (7), and a portion were alloted for liberation in the corn-borer infested areas of Ontario. The remainder were employed as breeding stock in the laboratory. Such breeding resulted in the liberation of an additional 1,700,000 individuals so that over 2,000,000 imported parasites have been liberated. Each step of this process has necessitated critical research in the selection of collection areas abroad, in the shipment to the United States, in the manipulation of the material after reaching this country, in rearing and breeding technic, in the selection of liberation sites in the new environment, in the exclusion of hyperparasites, and in the subsequent collections to determine whether the parasite species had become established.

Of the 12 species imported and liberated in the field a total of 6 species have been recovered in field collections by Jones and Caffrey (7) under circumstances indicating their permanent establishment as natural enemies of the corn borer in the United States.

DISEASE

Occasionally, small numbers of larvae succumb to what appears to resemble bacterial wilt. Attempts by several workers (3) to isolate the organism, with the objective of its possible artificial dissemination, have resulted negatively. Disease has not functioned as an important influence in the natural control of the borer.

CONTROL

The facts accumulated during the progress of these research activities have been utilized directly in the formation of suppression and

control methods. Ordinary and special farm procedure, as well as standard and specially constructed machinery, have been carefully studied in field and laboratory tests as reported in many publications (8) and (9).

Insecticidal investigations are still in progress. The status of other potential control methods, such as natural enemies, trap lights, attrahents, fumigation, etc., have been detailed in the preceding discussion. As indicated previously, mechanical measures, cultural practices, and other agronomic adaptations give the greatest promise in the solution of the corn borer problem at this time, since many of them are involved in the general requirement of utilizing or destroying all infested material or the residues thereof. The status of each phase is summarized briefly below:

Feeding to livestock direct from the field or in the form of ensilage or as finely cut or finely shredded material.

Burning surplus corn and other infested residues in piles, windrows, or in position. This problem has involved extensive research into various types of burning equipment, problems of combustion, fuel, gathering devices, and effects of burning upon soil conditions.

Plowing under completely of cornstalks, corn stubble, and other infested residues has been shown to depend for its effectiveness upon covering completely practically all plant debris in such a manner that it shall not again be dragged to the surface by subsequent cultivation before the moths emerge and that tillage operations should close all large crevices or cracks on the surface. This problem has involved a critical study of the habits of the borer when plowed under (detailed previously), research which demonstrated that the moths were unable to emerge in any numbers through even an inch of ordinarily well-tilled soil (3), field and laboratory research upon the best type of plows to accomplish effective plowing, and the effect of such plowing upon soil conditions.

Disking for small grains on corn lands has been shown to be a dangerous practice under corn borer conditions.

Inclusion of large sections of infested material in *manure*, under ordinary farm conditions, has been shown to be effective only when such material is buried deeply within the manure and trampled by livestock or otherwise.

Seasonal and *varietal* planting has been made the subject of extensive research by federal and state authorities throughout the infested areas and in some of the adjacent states. Agronomists are doubtless well informed concerning the objectives and results of such research. Briefly, all experiments have shown that under uniform conditions

late-planted corn is infested invariably by the corn borer to a lesser extent than early- or mid-season-planted corn. Also, that certain varieties or strains of corn are more tolerant to corn borer infestation than others. No variety of corn tested to date has consistently exhibited anything resembling immunity. Those varieties characterized by large, stiff stalks, enabling them to withstand the attack of the borer and the action of the elements without collapsing or breaking over appear to be more tolerant to borer injury than sorts lacking these characteristics.

These characteristics also enable the effective functioning of corn binders and other special machinery designed to cut infested cornstalks low preparatory to their further treatment. Recent developments in this phase of research have sought to embody the abovementioned characters and to develop corn which can be planted later than the normal or optimum period and still produce profitable yields.

During the season of 1927 several standard *varieties and special strains of Illinois corn* were tested under conditions of exposure to corn borer infestation in the experimental field of the federal corn borer laboratory at Monroe, Michigan.

The principal purpose of the experiments was to ascertain the performance, particularly the tolerance to corn borer attack, of the selected Illinois varieties and strains as a portion of the Illinois corn borer research program. The seed of certain of these selections was known to be infected by common corn diseases, particularly *Diplodia* and *Gibberella*, while seed of the same varieties or strains known to be disease-free or nearly disease-free were employed in the series with the object of comparing corn borer tolerance of the diseased and the disease-free sorts.

These experiments were conducted at the request and under the supervision of the entomologists and agronomists of the Illinois Experiment Station, the State Natural History Survey, and the U. S. Bureau of Plant Industry. W. P. Flint suggested the project, while the seed and instructions for field technic were furnished by Dr. J. R. Holbert, Dr. George H. Dungan, and F. D. Richey. Dr. Dungan assisted in harvesting the plats and has taken complete data regarding the performance of each strain.

Since the experimental plats were located in an area of corn borer abundance in Michigan, an indicative infestation developed in all plats. At this writing, however, the infestation data have not been compiled, so no report can be given of the results during this first year of the experiments. Plans were made to continue and enlarge upon this project during 1928.

Commercial utilization of corn residues as a phase of corn borer research has given encouraging indications and presents a distinct challenge to scientists and industrialists to aid in the solution of the corn borer problem, to provide a new source of income to the corn grower, and to create a value to plant material now largely wasted.

The fact that early-planted corn almost invariably exhibited the maximum infestation for any given locality at once suggested the possibility of utilizing such early plantings to function as *trap crops.* Actual attempts to employ this method of control have not proved successful and the present status of trap crops is that, while they may aid in concentrating infestation, they cannot be relied upon to protect the main crop of corn.

Insecticides have proved ineffective in protecting growing corn from injury by the corn borer in all experiments conducted to date, although this method has been successful in destroying large numbers of the borers in their early stages.

The choice of insecticides employed and the method and time of application has, of course, been based upon careful studies of the detailed behavior of the insect as well as upon the known facts concerning the chemical and physical properties of the insecticides used and the physiology of the plant and the corn borer. That the results have been negative should not discourage us from continuing to seek remedial measures of relief through the medium of insecitides.

CONCLUSION

Recent corn borer research developments have shown that mechanical measures and cultural practices have been effective in greatly curtailing the intensity of infestation and, with few exceptions, have kept the borer population below the point of serious commercial loss in the United States. Various supplementary measures, including corn breeding to produce varieties adapted to corn borer conditions, imported parasites, and possibly insecticides give promise of aiding in the ultimate solution of the problem.

Many minor details require further extensive research but such research should harmonize with projects having a practical significance, with due regard to the history of insect problems involving other introduced species. A comprehensive list of literature upon the corn borer, consisting of 114 foreign and 796 American references, should be scanned carefully by interested persons before embarking upon new research projects.

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AGRONOMIC RESEARCH ON THE EUROPEAN CORN BORER IN OHIO[1]

ROBT. M. SALTER, L. E. THATCHER, AND J. T. MCCLURE[2]

In its major fundamental aspects the European corn borer problem is entomological. The agronomist was invited to participate in the research program only when it became recognized that modifications in the methods of growing corn or in the kinds of corn grown might be necessary to meet certain entomological requirements. Although it clearly is the function of the entomologist to determine the relative effects of such modifications in reducing corn borer infestation, it is equally clear that their relative advantages should be studied by the agronomist, also since questions of yield and quality of crop are here concerned. Moreover, the best prospects for real progress would lie in a joint attack by entomologists and agronomists, thus bringing to bear on the problems a combined knowledge of the life history and habits of the insect and of the crop plant it damages.

In the Ohio program, to which this discussion will be largely confined, Ohio agronomists are working in closest cooperation with the Department of Entomology of the Ohio Experiment Station and with the Bureaus of Plant Industry and Entomology of the United States Department of Agriculture. In the following discussion no attempt will be made to draw a fine line of demarkation between the agronomic and entomologic phases of the work and it is hoped that it will be kept in mind that, whatever matters of infestation are discussed, the entomologists have been responsible for obtaining the data and are either jointly or wholly responsible for the conclusions reached.

[1]Paper read before the joint meeting of the Society and Section O of the American Association for the Advancement of Science at Nashville, Tenn., Dec. 27, 1927. The results on which this paper is based were obtained by the Department of Agronomy of the Ohio Agricultural Experiment Station in cooperation with the Bureaus of Plant Industry, Entomology, and Chemistry and Soils of the U. S. Department of Agriculture; the Department of Entomology of the Ohio Agricultural Experiment Station; and the Department of Farm Crops of Ohio State University. Special credit is due to L. L. Huber and C. R. Neiswander of the Department of Entomology of the Ohio Agricultural Experiment Station, under whose direction the entomological data were obtained; to G. W. Conrey for data on the relation of soil types to density of infestation; and to M. T. Meyers, Assistant Agronomist of the Ohio Agricultural Experiment Station and agent of the Bureaus of Plant Industry and Entomology of the U. S. Department of Agriculture, and J. S. Cutler for data resulting from the corn breeding investigations.

[2]Agronomist and Associate Agronomist of the Ohio Agricultural Experiment Station and Assistant Agronomist of the Ohio Agricultural Experiment Station and agent of the Bureau of Entomology, U. S. Department of Agriculture, respectively.

Prior to the cooperation of the agronomists, which began in 1924, the entomologists had begun a study of the relation of time of planting corn to infestation and had raised the question whether commercial varieties of corn possess different susceptibility to infestation or tolerance to damage. Indications had been obtained that infestation was reduced by late planting and that no practical differences in susceptibility to infestation existed among the varieties studied. These variety and date of planting studies have been expanded to include the taking of much more fundamental interpretative data regarding the rate of development and maturity of the crop in relation to the degree and character of the damage sustained. The location of this work has been at Bono, Lucas County, Ohio.

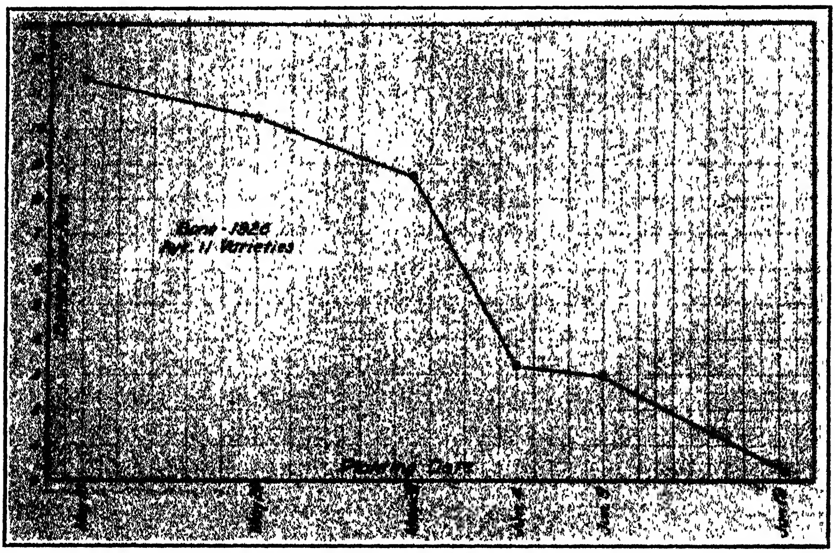

FIG. 1.—Relation of borer population to date of planting, Bono, 1926.

In Fig. 1 the average borer population of 11 varieties of corn plotted against the date of planting in 1926 is shown The decrease in borer population as planting date is delayed is fairly typical of the results secured in other years, the relative decrease for a given delay beyond the normal planting date having been found to be more or less independent of the general level of infestation.

The practical utility of late planting would appear to depend upon the answer to two questions, *viz.*, (1) Will the advantages of late planting continue to be manifest if all corn in a region is planted late? and (2) Does the advantage of the lower borer damage counterbalance the decrease in yield and maturity due to late planting?

The following expresses the present opinion of Ohio entomologists[3] on the first question.

"It must be admitted that no field experiments in Ohio or elsewhere have been sufficiently extensive in acreage to permit conclusive statements as to just what would occur if all corn were planted late. Such opinions and tentative conclusions as are now held are based on numerous field observations and upon artificially controlled experiments. Evidence from these two sources indicates that even though all corn were planted late it would possibly suffer no greater damage than the part that is planted late at the present time. Apparently the chemical and morphological character of the smaller corn plants is inimical to the physiology of the borer."

Considerable data have been secured from which a partial answer to the second question can be given. In addition to four years' work at Bono, where a series of corn varieties of different seasonal requirements are planted on successive dates and both yield and maturity determined, similar studies have been made at Wooster in northeastern Ohio, on the Paulding County Experiment Farm in northwestern Ohio, at Columbus in central Ohio, and on the Hamilton County Experiment farm in southwestern Ohio. Appreciable corn borer infestation exists only at Bono. The purpose of the other experiments has been to obtain data on yield and maturity in anticipation of possible future need.

TABLE 1.—*Yields relative to first planting date taken as 100.**

Planting date	Burr Leaming	Leaming	Clarage	Golden Glow, Medina Pride	N. W. Dent, Van Wye, Wisconsin 25
May 8–10	100	100	100	100	100
	100	100	100	100	100
May 19–20	97	102	95	106	101
	102	99	97	101	88
May 29–31	101	96	93	102	99
	100	96	99	97	107
June 9–10	88	84	80	87	89
	93	83	93	101	142
June 19–20	70	73	69	85	75
	99†	98†	101†	105†	167

*Average data for 1923, 1924, and 1926 given first with data for 1927, next.
†Planting date June 15.

In Table 1 are shown the relative yields obtained at Bono for a number of varieties arranged in series from late- to early-maturing sorts. The yield for the first planting (May 8 to 10) has been taken as 100 in all cases. The relative yields have been calculated on the

[3]HUBER, L. L., and NEISWANDER, C. R. Entomological research on the European corn borer in Ohio. Jour. Amer. Soc. Agron., 19:128–137. 1927.

basis of the actual yields of shelled corn with a uniform moisture content of 15.5%. From the average of the first three years' results it is observed that the yields of all varieties decreased with the later planting, the decrease being greatest for the late-maturing varieties. The results secured during the 1927 season are not in harmony with the previous three years' results, the late plantings having shown up much more favorably than in previous years. This fact is probably the result of the highly abnormal weather which characterized the past season, conditions for growth and maturity of the crop having been more favorable in September than in the preceding month of August.

TABLE 2.—*Yields relative to highest yield of Burr Leaming taken as 100.**

Planting date	Burr Leaming	Leaming	Clarage	Golden Glow, Medina Pride	N. W. Dent, Van Wye, Wisconsin 25
May 8–10	100	82	81	77	63
	98	91	86	82	44
May 19–20	96	85	77	82	62
	100	90	83	82	40
May 29–31	100	81	75	79	60
	100	96	85	80	48
June 9–10	88	69	66	67	55
	93	83	80	83	63
June 19–20	69	60	60	68	46
	99†	98†	87†	105†	74

*Average data for 1924, 1925, and 1926 given first with data for 1927, next.
†Planting date June 15.

In Table 2 are shown the relative yields for the same varieties based on the highest yield of the highest yielding variety taken as 100. It is evident from the data that, so far as total yield of dry grain is con-

TABLE 3.—*Maturity as indicated by average percentage moisture at husking time, Bono, Ohio.**

Planting date	Burr Leaming	Leaming	Clarage	Golden Glow, Medina Pride	N. W. Dent, Van Wye, Wisconsin 25
May 8–10	26.8	31.6	25.7	36.88	20.3
	39.32	35.98	36.44	34.19	36.62
May 19–20	28.6	27.8	25.9	32.41	21.9
	41.78	37.72	39.62	34.97	37.18
May 29–31	33.1	31.0	29.2	33.07	22.0
	36.0	32.95	32.34	28.46	43.36
June 9–10	37.3	34.5	31.9	35.38	23.9
	44.24	42.07	37.89	37.22	24.75
June 19–20	44.1	42.9	37.8	39.36	28.3
	34.12†	32.03†	31.35†	29.7†	22.81

*Average data for 1924, 1925, and 1926 given first with data for 1927, next.
†Planting date June 15.

cerned, the early varieties are actually inferior to the later varieties for late planting. This is true in spite of the fact that the latter carry much larger moisture contents at husking time as shown by the data given in Table 3. It is possible, of course, that high moisture content at husking might so increase the danger of spoilage under ordinary conditions of handling the crop that the use of late varieties for late planting would be hazardous. It is entirely possible, however, that methods of artificially drying or otherwise handling soft corn now being investigated by agricultural engineers may offer a solution of this difficulty.

In the experiments to which the foregoing data apply, a uniform rate of stand of three plants per hill has been employed. The question has been raised whether the relative standing of the earlier and smaller growing varieties could not be improved by a thicker rate of planting. To answer this question an experiment was started in 1927 in which five early-maturing varieties, Wisconsin 25, Wisconsin 8, St. Paul's White Dent, Minnesota 13, and M. A. C. Yellow Dent were each grown at rates of 3, 4½, and 6 plants per hill in triplicate plats planted on June 10. The average yields for all varieties were 59.3 bushels per acre for the 3-plant rate, 56.5 bushels for the 4½-plant rate, and 53.6 bushels for the 6-plant rate. Wisconsin 25 was also planted at the same three rates on each of six different dates. The average yields for all planting dates were for the 3-plant rate, 41 9 bushels; for the 4½-plant rate, 47.9 bushels; and for the 6-plant rate 39.2 bushels. Another experiment was conducted at Wooster in 1927 in which Wisconsin 25 corn was planted May 15 on fertile soil at rates of 1, 2, 3, 4, 5, and 6 plants per hill. The corresponding yields were 18.9, 37.0, 49.3, 52.0, 69.9, and 61.2 bushels per acre, respectively. The results for this single year cannot be interpreted in a manner to answer the question at hand. Obviously further study is needed.

The more general relation of rate of planting to infestation and damage has been studied for three years. The results of the first two years were not conclusive, probably due to the fact that insufficient infestation occurred in these plantings. The results obtained in 1927 were apparently satisfactory. The data are shown in Table 4. In this season Burr Leaming corn, planted on May 15, was grown in triplicate plats with 1, 3, and 5 plants per hill. Increasing the rate of planting from 1 up to 5 plants has not appreciably affected the percentage of stalks infested, has reduced the number of borers per infested stalk, and has considerably increased the proportion of broken stalks, the latter resulting presumably because of reduced stalk diameter and a consequent lower resistance to breakage. Considered in connection

with the obvious lack of any significant advantage in yield it appears that the planting of corn at higher than the normal 3-plant rate offers no practical advantage for corn borer conditions.

Studies by the entomologists of the degree of infestation and borer population in the varieties included in the varietal and date of planting experiments have revealed no significant evidence of any marked difference in susceptibility to infestation. Fig. 2 shows the average percentage of infestation for all planting dates for each of seven varieties for the years 1924 to 1926, inclusive. The data are arranged from left to right in the approximate order of the season required for

TABLE 4.—*Data from rate of planting test, Bono, 1927, Burr Leaming corn planted May 15.* Averages of triplicate plats.

Plants per hill	Infestation %	Borers per infested plant	Broken stalks %	Yield in bushels per acre*
1	67.2	1.72	4.6	55.6
3	67.9	1.20	9.8	83.6
5	60.4	.91	12.9	78.1

*Reduced to 15.5% moisture.

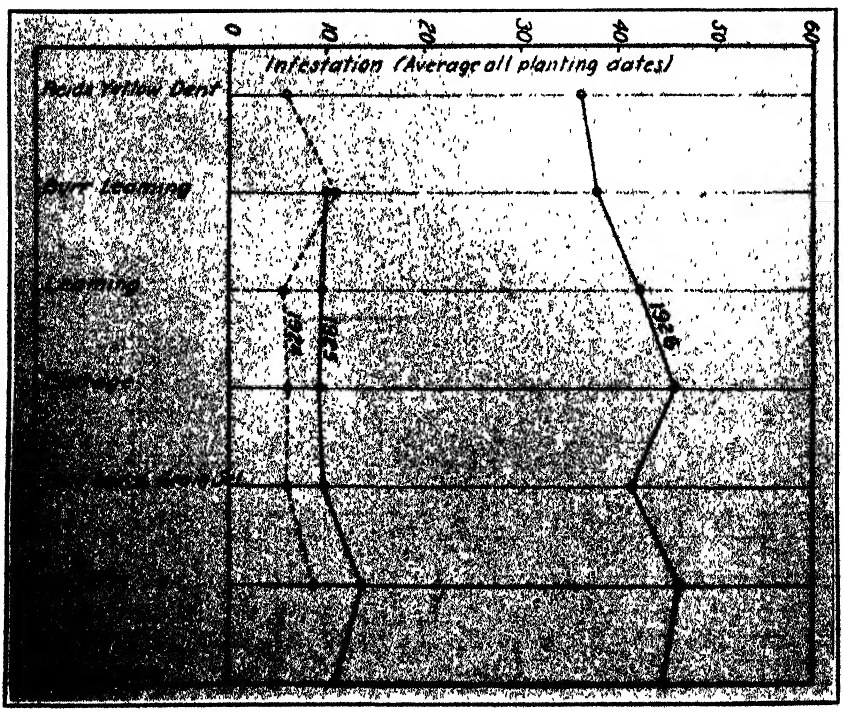

FIG. 2.—Infestation of seven varieties of corn at Bono, 1924, 1925, and 1926.

maturity by the different varieties, the later varieties being on the left. There is some indication that the later varieties are somewhat less heavily infested than the earlier-maturing sorts. Borer population counts in the 1927 experiments seem to substantiate this idea. A possible explanation for this difference will be presented later.

A question of fundamental interest to both entomologists and agronomists is the cause of the corn borer's preference for early- as compared with late-maturing varieties, and, as the entomologists have shown, for normal as compared with subnormal corn of the same planting. A natural assumption would be that the mere size of the plant or its leaf area at the peak of the moth flight (approximately July 10 to 15 at Bono, Ohio) might be the determining factor. However, olfactometer studies, in which female corn borer moths have been given a choice between distillates from early- and late-planted corn or from vigorous and weak corn plants have revealed a preference for the distillates from the older and from the more vigorous plants. Such a preference can only be due to the presence in the distillates from the older and vigorous corn of some odoriferous compounds which are either absent or present in smaller quantity in the distillates from the younger and weaker corn. That the preference shown by moths in the field for vigorous or more mature corn may be due to the presence of these attractant compounds would appear as a logical assumption. Plant physiologists and chemists have been engaged in an attempt to isolate and identify these attractive substances, and to determine the location in the plant of the cells responsible for their production. Some progress has been made, but much future work will be required before results of practical utility can be had.

Considerable interest has centered in the question as to whether the attractive character of the larger and more vigorous corn is correlated with size of plant or whether it is more closely correlated with the actual stage of development which the plant has attained at the period of moth flight. It was impossible to give an answer to this question prior to the work of the past season because of the failure to secure accurate data upon the rate or stage of development in the various plantings. While detailed data on height, leaf area, etc., had been taken at regular intervals during the season, such data as had been secured relative to rate of development as measured by date of silking, date of tasseling, etc., had been too general in their character to permit of treatment by statistical methods. In 1927 the plan was adopted of securing more precise records of the silking dates of all plantings. Dated tags were placed upon each stalk in a representative row of each plat or planting on the day that silking was observed.

After silking was completed the average silking date for each plat or planting was determined. While it was realized that the indication of rate of development afforded by the average date of silking might not correlate perfectly with the stage of development attained by the plant at the moth flight period, it seemed fair to assume that, barring any special conditions which might interfere with the normal development of the plant, the correlation should be sufficiently close for the purpose at hand. It is hoped that in the future some morphological or physiological indicator of stage of development may be worked out which may be applied to the plant during the moth flight period.

The material which seemed best fitted for determining the correlation of infestation with height and silking date was data secured from a planting made as a part of the corn breeding program. The other phases of the breeding work will be considered later.

TABLE 5.—*Correlation studies with certain characters.*

Characters studied	1st planting	2nd planting
	Zero order correlation coefficients	
Date of silking with infestation	—.5548 ± .021	—.4296 ± .026
Infestation with height	.3773 ± .026	.4702 ± .025
Date of silking with height	—.1446 ± .030	—.5161 ± .024
Damage with date of silking	—.7919 ± .011	—.3972 ± .027
Infestation with damage	.7804 ± .012	.5686 ± .022
	First order partial correlation coefficients	
Date of silking with infestation (height constant)	—.5458 ± .021	—.2473 ± .030
Infestation with height (date of silking constant)	.3609 ± .026	.3213 ± .029
Date of silking with damage (infestation constant)	—.6899 ± .016	—.2058 ± .031
Infestation with damage (date of silking constant)	.6715 ± .017	.4803 ± .024

In 1927 some 160 selfed lines and 500 crosses between selfed lines and various native varieties and types from other countries were planted on May 13 and on June 10 at Bono. The selfed lines and crosses represented material obtained through the cooperation of corn breeders of 11 states and the United States Department of Agriculture. Its diverse character and the fact that it came from many sources made it a fairly good cross section of the corn of the country. Each culture was grown in a single row of nine hills. The succession plantings were so planned as to have the corn plants in stages of growth relatively attractive and unattractive to the moths during the time of maximum oviposition. After eliminating those rows with less than two-thirds of a full stand, 485 rows were available in the first planting and 453 in the second planting. Certain cultures such as

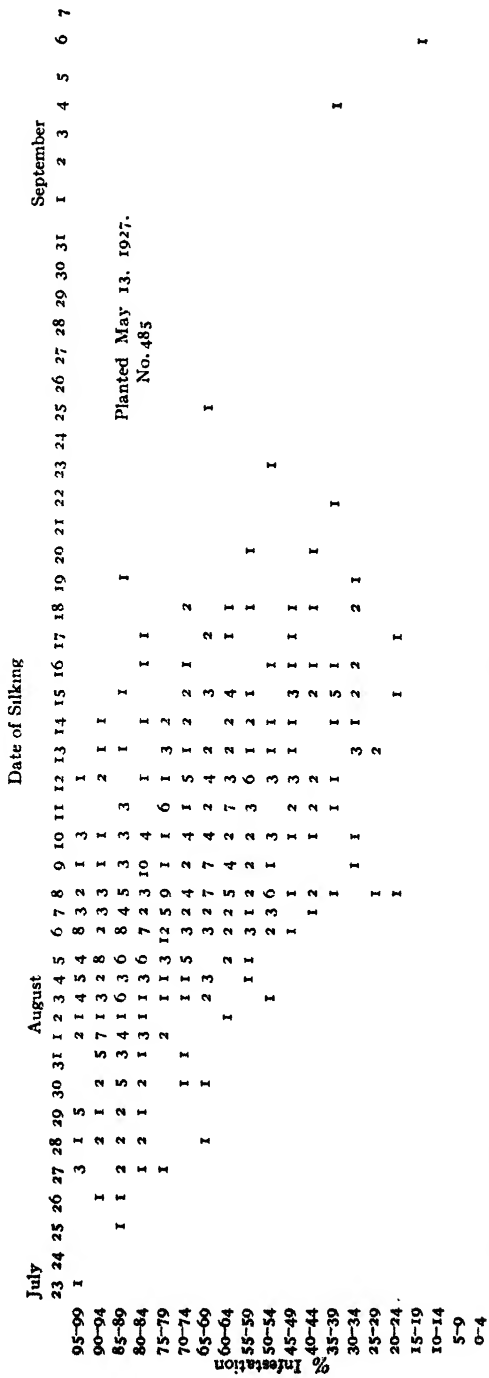

FIG. 3.—Scattergram showing relation of infestation to date of silking in corn planted May 13, 1927, at Bono.

Maiz Amargo (the so-called bitter corn of Argentina) and China High Ear had failed to silk by September 10 in the second planting and were eliminated. Data were secured for each culture on average date of silking, height to tip of longest leaf at time of moth flight, percentage of infestation, percentage of infested stalks broken, and yield. In Table 5 are shown the results of certain correlation studies which have been made by Meyers and Cutler upon the relationship existing between these characters.

Of special interest are the zero order correlation coefficients of —0.5548 and —0.4296 secured between percentage of infestation and date of silking for the first and second plantings respectively. The "scattergram" showing this relationship for the first planting is shown in Fig. 3 and for the last planting in Fig. 4. The results for the two plantings are combined in Fig. 5. At the same time, significant correlations between infestation and height of 0.3773 for the first planting and 0.4702 for the second planting were obtained. It is to be noted that in the early planting a very high partial correlation of —0.5458 was obtained between percentage of infestation and silking date when height was held constant. When stage of development as measured by date of silking was held constant a lower partial correlation of 0.3609 was obtained between height at time of moth flight and percentage of infestation, indicating that stage of development is the important factor in determining the attractiveness to the moths as measured by the percentage of infestation. In the later planting, the stage of development appears to have had a less important relation to infestation, perhaps due to the fact that, because of the late planting, all cultures were more nearly at the same stage of development and had not reached the attractive stage at the time of maximum moth flight.

The singificance attached to the apparent relation between stage of development and infestation will be noted in the discussion to follow.

To return to the date of planting, it is obvious that as planting is delayed, the stage of development reached by the plant at the time the moths are in flight will be progressively less advanced. A study of the relation of the average silking date to the planting date is of interest in this connection. In Fig. 6 this relationship is shown for the six varieties included in the 1927 varietal and date of planting experiment at Bono. It appears that the delay in silking incident to a given delay in planting is nearly equal for all varieties irrespective of their seasonal requirements. This follows from the fact that the curves for the individual varieties are approximately parallel. They are also approximately linear, indicating a general proportionality between delay in planting and delay in silking.

Planted June 10, 1927.
No. 453

% Infestation	August											Date of Silking										September						
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7
95–99																												
90–94																												
85–89																												
80–84																												
75–79							1																					
70–74								1																				
65–69		1				1	2									1												
60–64			1	2		1	1	4		1																		
55–59				1	2	2		1	1										1									
50–54		1		1	1	1	8	4	4	5	1	2																
45–49					2	2	4	3	6	2	1	1	2	1				1	1									
40–44	1		1	1	3	4	12	8	4	1		2	1	2	1		1	1			1							
35–39					2	6	7	5	4	1	1		1	2														
30–34		2			1	3	8	7	9	5	5	6	4	2	1		2		1									
25–29		1			3	3	4	8	7	7	2	6	2		4	5	3	1				1						
20–24						1	6	4	9	5	4	4		4	2	1	1		2	1	2							
15–19				1	3	2	1	6	5	7	3	5	3	3	6	2	3	3		1								
10–14						3	4	4	4	6	5	3	5	4	1	2	2	2	1	1	1							
5–9					3	1	3			2		2	1	1	2			1	1	2								
0–4					1				1	2	2		1	3	1	3	1			2	1	1	1				1	

FIG. 4.—Scattergram showing relation of infestation to date of silking in corn planted June 10, 1927, at Bono.

COMBINED DATA FOR FIRST AND SECOND PLANTINGS

Date of Silking

% Infestation	July 23	24	25	26	27	28	29	30	31	August 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
95–99	1				3	1	5			2	1	4	5	4	8	3	2	1	3		1			
90–94				1		2	1	2	5	7	1	3	2	8	2	3	3	1	1		2	1	1	
85–89			1	1	2	2	2	5	3	4	1	6	3	6	8	4	5	3	3	3		1		1
80–84					1	2	1	2	1	3	1	1	3	6	7	2	3	10	4		1		1	
75–79					1					2		1	1	3	12	5	9	1	1	6	1	3	2	
70–74								1	1			1	1	5	3	2	4	2	4	1	5	1	2	2
65–69						1		1				2	3		3	2	7	7	4	2	5	2		3
60–64											1			2	2	2	5	4	2	7	3	3	4	4
55–59													1	1	3	1	2	2	2	3	6	1	3	3
50–54												1			2	3	6	1	3		4	1	2	1
45–49															1		1		1	2	3	1	1	5
40–44																1	2		1	3	2	1	1	5
35–39																	1			1	1		1	7
30–34																		1	1		2	3	1	3
25–29																	1				1	2		3
20–24																	1							1
15–19																							1	3
10–14																								
5–9																								3
0–4																								1

% Infestation	August 16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	September 1	2	3	4	5	6	7
95–99																							
90–94				1																			
85–89																							
80–84	1	1																					
75–79		1																					
70–74	1		3																				
65–69	1	4								1	1												
60–64	1	2	5		1																		
55–59	2		2	1	1									1									
50–54	2	8	4	4	5	1	2	1															
45–49	3	5	4	6	2	1	1	2	1				1	1						1			
40–44	5	12	9	4	2		2	1	2	1		1	1			1							
35–39	7	7	5	4	1	1	1	1	2														
30–34	5	8	9	10	5	5	6	4	2	1		2		1									
25–29	3	4	8	7	7	2	6	2		4	5	3	1				1						
20–24	1	7	4	9	5	4	4		4	2	1	1		2	1	2							
15–19	2	1	6	5	7	3	5	3	3	6	2	3	3		1								1
10–14	3	4	4	4	6	5	3	5	4	1	2	2	2	1	1	1							
5–9	1	3		2				2	1	1	2		1	1	2								
0–4				1	2	2		1	3	1	3	1			2	1	1	1				1	

FIG. 5.—Scattergram showing relation of infestation to date of silking. Combination of results from corn planted May 13 and June 10, 1927, at Bono.

Thirty-six days' delay in planting (from May 10 to June 15) has occasioned delays in silking as follows: Burr Leaming, 21.0 days; Leaming, 21.0 days; Clarage, 21.0 days; Golden Glow, 22.0 days; Medina Pride, 23.6 days; Wisconsin 25, 21.2 days; average, 21.6 days. As an average for this period, each day's delay in planting has delayed silking by 0.60 day. While the curves are in general linear, there are minor deviations from true linearity. It will be noted that, with few exceptions, the direction of these deviations are the same for all curves, a rather remarkable fact considering the range of varieties considered and the actual spread in the silking dates.

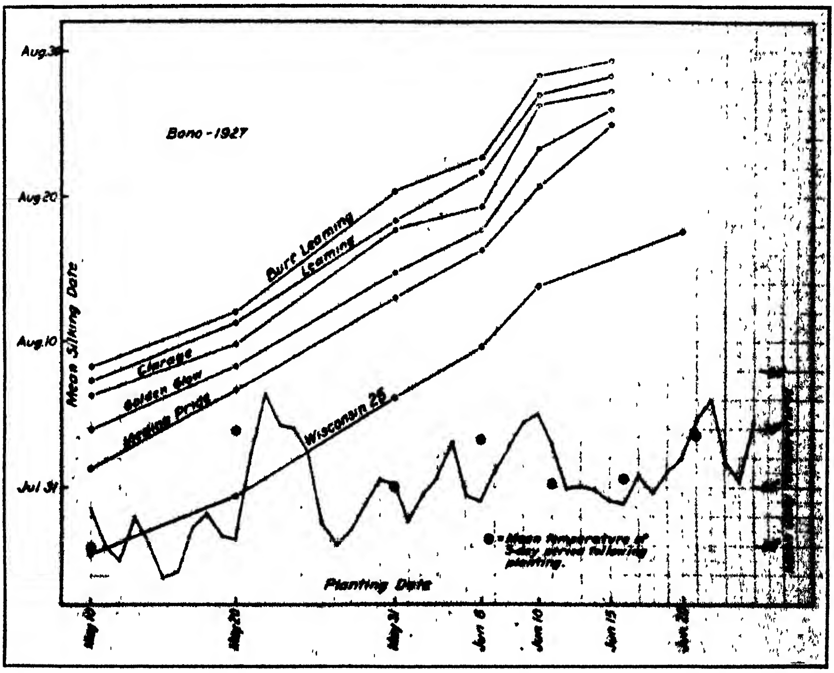

FIG. 6.—Relation of date of silking to date of planting, Bono, 1927.

The only explanation which the authors are able to suggest is that weather or soil conditions at planting time are reflected more or less accurately in the silking date. The mean daily temperatures during the planting period are plotted in the figure and the average temperature of the 5-day period following each planting is indicated. It will be observed that a curve connecting these mean temperature points would in each case break in an opposite direction to the breaks in the silking date curves. It would appear that where a given planting is followed by a period of low mean temperature, the delay in planting

results in a delay in silking which is greater than that normally to be expected, and vice versa. If low temperatures at planting time tend to delay development as measured by silking date and if delayed development results in reduced corn borer infestation, the question might logically be raised as to whether the general level of infestation in Ohio in 1927 may not have been reduced in consequence of the facts that a majority of the corn acreage was planted in June and that the mean temperature for that month was with one exception the lowest in 67 years, according to official records for Toledo which is 12 miles due west of Bono.

In general, it would appear that any factor which slowed up the initial rate of development of the corn crop might be expected to reduce infestation. The somewhat lower infestation of late-maturing as compared with early-maturing varieties agrees with their slower rate of development as indicated by their later dates of silking.

In a preliminary experiment conducted at Bono in 1927 the effectiveness of several methods of artifically slowing up the early development of corn upon infestation was compared. The corn was planted at the normal time, subjected to various treatments designed to slow up development until the period of moth flight was practically over and then speed up later development by a topdressing with complete fertilizer. It is obvious that in such an experiment, the average silking date might be an imperfect indicator of the stage of development of the crop during the moth flight period. The special treatments given to delay early development were (1) listing or planting in furrows, (2) cutting the plant off at various heights on July 1, and (3) biological reduction of available soil nutrients by incorporation of carbonaceous organic materials in the soil. In Fig. 7 are shown the curves for height of plant and average silking date for selected plats in this experiment. The special treatments are indicated and data on percentage of infestation and yield of marketable corn reduced to 15.5% moisture are shown.

Each of the special treatments was effective in reducing infestation, the most marked effect being produced by the incorporation of straw in the soil by disking previous to planting. The infestation in this case was 14.2% compared to an average of 69.2% for the check plats. The reduced infestation on the listed plat, 27.6%, is interesting in view of the fact that listing is a practice whose adoption would not necessarily increase the cost of growing corn and might be expected to increase the yield on some soils. The fertilizer treatment given appears to have been effective in preventing any appreciable reduction in yield except in the case of the straw treatment plat which yielded

only 80% as much as the checks. A study of the effects of lighter applications of straw as well as of graded applications of cut corn stover is planned for the ensuing year. While no definite conclusions are warranted from the first year's data, the results lend encouragement to undertaking more intensive investigations along these general lines.

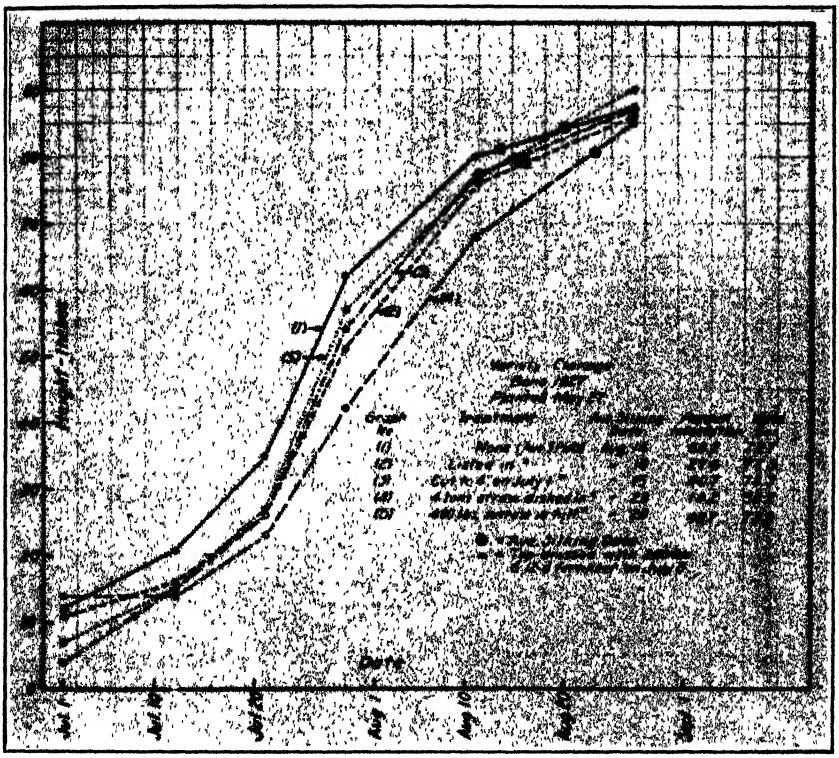

FIG. 7.—Results of various methods of retarding early development of corn at Bono, 1927.

A supplementary test of a more severe clipping treatment was also conducted at Bono in 1927 on what is known as the Chio field. Three varieties of corn, Burr Leaming, Medina Pride, and Wisconsin 25, planted on May 27, were clipped to a height of 9 inches on July 14. Fig. 8 shows the appearance of the plats immediately after clipping. In addition to delaying the development of the crop, such a treatment given shortly after the peak of the moth flight might be expected to destroy many eggs and young corn borer larvae. In Fig. 9 are shown the curves for height of plant in the clipped and unclipped plats. The average silking dates are indicated and data are shown for borer

population and yield. It is evident that borer population was markedly reduced by clipping. The yields were lowered to such an extent, however, as to render the treatment uneconomical for the level of borer damage obtaining in the test. The largest reduction in yield occurred in the case of the earliest corn, probably due to the fact that its more advanced stage of development at the time of clipping made recovery more difficult.

FIG. 8.—Appearance of plats immediately following clipping to 9 inches on July 14.

A factor which might be expected to be highly important in influencing the rate of development of the corn crop, and hence, indirectly, the degree of corn borer infestation, is the productivity of the soil. Of most importance would probably be natural or artificially induced variations in drainage, reaction, and fertility, using the latter term in its narrower sense as indicating the ability of the soil to yield up plant nutrients. That soil differences may markedly influence the rate of development of the crop is clearly indicated by data secured during the past season on a single variety of corn, Burr Leaming, planted on approximately the same date at Wooster and Bono. The soil at Bono is a heavy, alkaline, dark-colored Toledo clay of high natural fertility. The Wooster soil is a medium-textured, acid, light-colored Canfield silt loam of low natural fertility. Both tracts are artificially drained.

In Fig. 10 are shown the curves for height of plant and average silking dates for both untreated and fertilized plats for the two locations. The fertilizer treatments given are also indicated and data are given for the yield of dry corn (15.5% moisture). Without fertilizer treatment the average silking date at Bono was August 21 and at Wooster September 21, a difference of exactly one month. To produce an equal difference in time of silking at Bono by varying the planting date would require a difference of 50 days in time of planting, assuming that each day's delay in planting advances the silking date by 0.6 day. It is impossible to differentiate clearly between the influence of edaphic and climatic factors in producing the differences

in rates of development noted at Bono and Wooster. The mean monthly temperatures for the two locations were nearly the same for the period of April to September, inclusive, the maximum difference for any one month being only 0.8°. However, the total rainfall during the same period was 21.6 inches at Wooster and only 15.8 inches at Bono. That soil differences were of relatively large importance is at

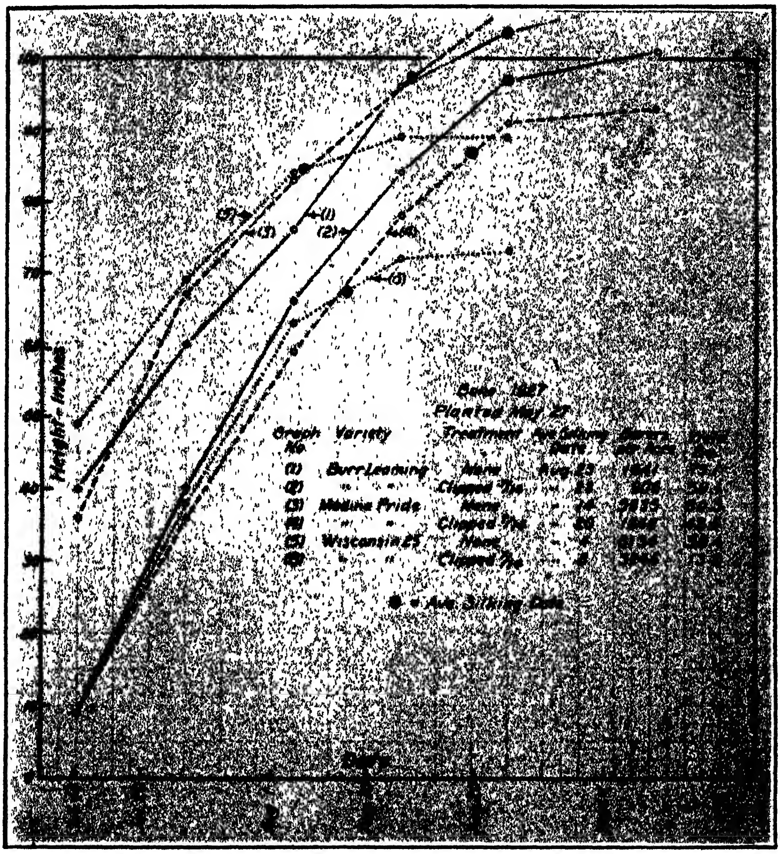

FIG. 9.—Results of clipping corn to 9 inches on July 14 compared with no treatment.

least indicated by the results secured on the fertilized plats. At Bono the natural level of productivity was so high that fertilizer additions were without significant effect. At Wooster each increase in the level of fertilizer treatment increased the rate of growth, shortened the period from planting to silking, and increased the yield.

An interesting relation which is probably dependent in part upon soil differences is the relative reduction in yield occasioned by delaying

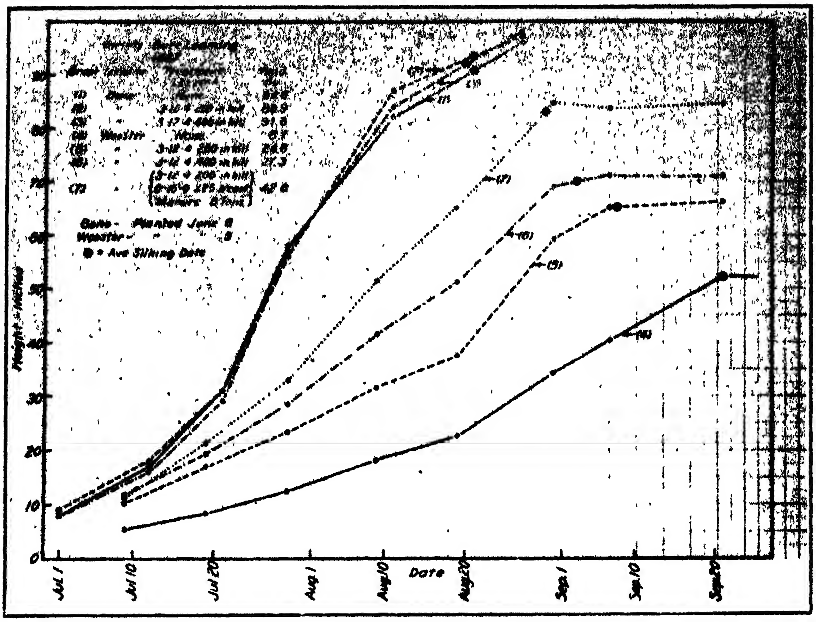

FIG. 10.—Results of natural and artificially induced variations in soil productivity on development of corn at Bono and at Wooster in 1927.

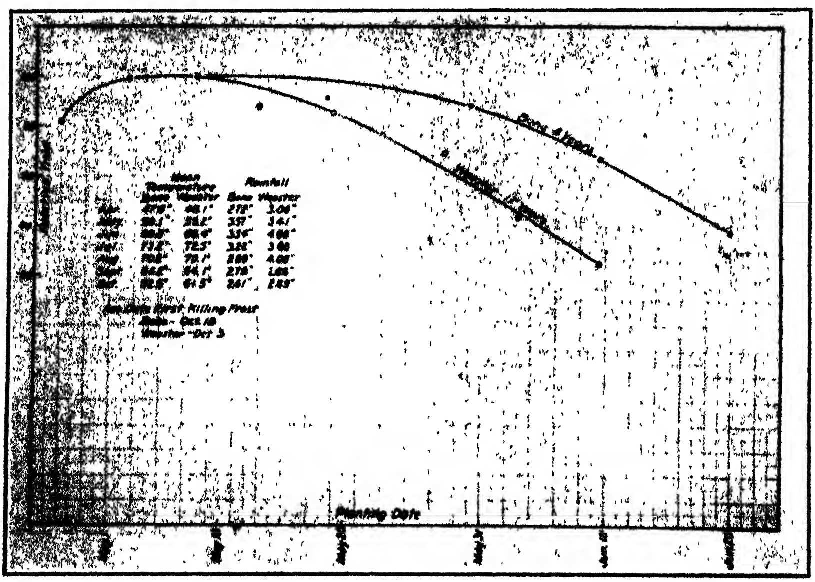

FIG. 11.—Relation of time of planting to yield of Clarage corn at Bono and at Wooster.

the planting date at Wooster and at Bono. In Fig. 11 are shown curves relating to planting date and the yield of Clarage corn during 17 years at Wooster and 4 years at Bono. While climatic differences, especially the 13 days difference in date of the first killing frost, probably play a part in causing the more serious effects of late planting on yield noted at Wooster, the slower development of the crop due to poorer soil conditions is probably also important. The conclusion may be warranted that late planting as a means of reducing corn borer infestation will be more apt to be found profitable under good than under poor soil conditons. On the other hand, there is some evidence for suggesting that it is only in regions of high soil productivity that the corn borer may be expected to accumulate to such an extent as to result in serious damage to the corn crop.

Entomologists have observed that the accumulation of corn borers in different regions has varied greatly, even where the duration of infestation has been the same. Through their efforts, and through the cooperation of Drs. E. N. Transeau and H. C. Sampson of Ohio State University, an ecological survey of the vegetation of the infested areas of the United States and Canada was made and an important relationship of infestation accumulation to natural vegetative types was found. In recognition of the probable significance of soil type as an ecological factor in this connection, the suggestion was made that the soil survey division of the Ohio Experiment Station cooperate in an attempt to determine any correlation of soil type with corn borer infestation in northern Ohio. Accordingly, Dr. G. W. Conrey and his assistants, in cooperation with the Bureau of Chemistry and Soils of the U. S. Dept. of Agriculture, made observations on the soil types of some 350 fields upon which the 1927 infestation counts were made by Ohio entomologists. The results of this study established the fact that infestation accumulation is correlated with soil type and point strongly to the value of soil survey data in predicting the areas in which the insect may be expected to constitute the most serious menace. The following tentative conclusions have been drawn by those engaged in this survey study.

1. The greatest accumulation of corn borers will probably occur on the best corn soils. In western Ohio and adjoining regions these soils are chiefly the Brookston silty clay loam, Clyde silty clay loam in the glacial limestone area, and Brookston clay and Toledo silty clay within the "lake plain." These are the dark-colored soils of the area and are naturally poorly drained, artificial drainage having been required for their utilization.

2. Next to the dark soils in infestation will probably be the well-drained, light-colored soils. In the glaciated limestone area these

include the Bellefontaine and Miami silt loam chiefly. In the "lake plain" the well-drained, light-colored soils include the Lucas and beach ridge phase of the Fox soils, chiefly fine sandy loams and loams. The gravelly terraces, Fox loam and silt loam, should be included in this group. These are fertile soils and produce good corn.

3. The poorly drained light-colored soils, such as the Crosby, Napanee, and Fulton, are fair to poor soils and should show a lower infestation than those previously mentioned.

4. The heavy light-colored galcial soils from sandstone and shale occurring in northeastern Ohio and adjacent parts of Pennsylvania and New York (Mahoning, Ellsworth, and Volusia) can be classed as fair to poor corn soils. To date there has been little or no infestation in corn grown on them. The climatic factor is probably important in contributing to the lateness of the corn grown in this region. Heavy infestation may be expected on the gravelly terraces (Chenango loam and silt loam) and on the flood plain soils (Chagrin silt loam and Papakating silcy clay loam). Dark soils throughout the upland (Chippewa silty clay loam) are very limited in extent and unimportant but may be expected to show a higher infestation than the associated light-colored soils.

Corn breeding in relation to the corn borer was begun in 1926 and is directly in charge of M. T. Meyers, working in cooperation with the Farm Crops Department of the Ohio State University and the United States Department of Agriculture. The work is being carried on at Bono, Columbus, and Wooster. The corn breeders of 11 states cooperated splendidly in supplying many selfed lines and crosses in 1926 and 1927, making possible the rapid development of an extensive program.[4]

Crosses between the selfed lines sent in by different states were made in 1926. These F_1 hybrids, together with additional crosses supplied in 1927, were grown in 1927. The scope of the 1927 plantings at Bono has already been indicated.

The prime objectives of the corn breeding program are, first, the discovery of any characters in the corn plant which may contribute to reduced corn borer infestation or damage, and second, the development of adapted, high-yielding hybrids which possess the desired

[4]The following breeders contributed material for these studies: G. N. Hoffer, LaFayette, Ind.; C. M. Woodworth, Urbana, Ill.; J. R. Holbert, Bloomington, Ill.; M. T. Jenkins, Ames, Ia.; H. A. Wallace, Des Moines, Ia.; T. A. Kiesselbach, Lincoln, Nebr.; A. M. Brunson, Manhattan, Kans.; C. R. Burnham, Madison, Wis.; R. G. Wiggans, Ithaca, N. Y.; D. F. Jones, New Haven, Conn.; F. D. Richey, Washington, D. C.; L. J. Stadler, Columbia, Mo.,; Wm. H. Eyster, Orono, Me.; H. K. Hayes, St. Paul. Minn.; and G. H. Stringfield, Wooster, Ohio.

characters in the greatest degree possible. Detailed study has been made of the life history of the selfed lines and crosses and careful observations have been made of all morphological characters which might be expected to have any influence on infestation or damage by the borer.

Attention has already been called to the relation discovered between infestation and rate of development as indicated by silking date. This work points clearly to the futility of selecting a late, slow-developing strain which has a low attractiveness to the moths and crossing it with an earlier strain expecting to retain this low attractiveness in the early segregates. On the other hand, the difference in attractiveness of corn in different stages of development is undoubtedly largely a chemical one and it is entirely possible that variations in this chemical attractiveness occur in corn of the same relative stage of development. Furthermore, variation in the percentage of establishment of the larvae may be associated with physiologic or morphologic characters of the plant. By studying the cultures which deviate widely in infestation from that predicted on the basis of the trend of the regression equation relating infestation and state of development, one might expect to find such differences as may exist and to discover the specific conditions which account for them

TABLE 6.—*Borer population and broken stalks for different varieties in Essex County, Ontario, 1926.**

	Average of three planting dates.	
Variety	Borer population per stalk	Percentage of stalks broken
Minnesota 16	6.0	23.3
Minnesota 24	4.6	21.5
Clarage	4.2	19.8
Minnesota 22	3.8	18.8
Bailey	5.7	16.5
White Cap	4.7	16.5
Golden Glow	4.3	15.8
Burr Leaming	4.3	11.6

*Each variety represented by triplicate plats on each of three planting dates.

Studies are also being made of the performance of large numbers of corn hybrids when planted late, with the hope that some may be discovered that will prove better adapted to late planting than present commercial varieties. That hybrid vigor resulting from the crossing of inbred strains may in itself help to compensate for the reduction in yield attending late planting is evidenced by the favorable position of Burr Leaming corn in the table of yields previously reported for the varietal and date of planting experiments at Bono. Burr Leaming, which is a double cross developed by the Connecticut

Station, has consistently given larger yields when planted June 9 to 10 than any of the standard varieties planted at the normal planting period of May 10 to 20.

Considerable evidence has already been secured that some strains of corn can tolerate a given number of borers with less breakage of stalks and consequently less damage and reduction in yield than others. Strains which possess sturdy, thick stalks and which remain vegetative after the ear is well dented appear to offer this advantage. Burr Leaming possesses these characteristics to a notable degree. In Table 6 are presented data on borer population and stalk breakage secured from a planting of eight varieties of corn made in a heavily infested area in Essex County, Ontario, in 1926. The favorable position of Burr Leaming corn is apparent. Ruggedness of stalk is being given considerable emphasis in the breeding program.

Several other agronomic problems are being investigated in Ohio which have a bearing upon the corn borer problem but which cannot be discussed in detail at this time. Among these may be mentioned the study of crop rotations adapted to corn borer conditions, the value of the fertilizing constituents lost when corn stover is burned, and the value and conditions necessary for the production of synthetic manure from shredded corn stover.

In conclusion it should be stated that several of the methods for reducing corn borer infestation being studied by the agronomists involve certain reductions in yield or monetary income. Examples are the late planting of corn, delaying the early development of corn by heavy applications of carbonaceous materials to the soil or by severe clipping, and the substitution of less valuable crops for corn in the rotation. The practicability of any of these methods will depend upon the level of corn borer injury obtaining and the extent to which such injury may be offset by the methods in question. More evidence is needed upon the relation of damage to the level of corn borer infestation before definite conclusions may be reached regarding the utility of these methods.

Many phases of the agronomic corn borer research program are still in the preliminary stages and it is to be hoped that the necessary support for their continued development will be forthcoming. It is especially to be desired that the splendid spirit of cooperation which has existed among all the agencies which have been engaged in the corn borer research work may continue to be manifest in the future.

COOPERATION IN CORN BORER RESEARCH[1]

CARLETON R. BALL [2]

INTRODUCTION

Cooperation means operating together. The definition is simple, the theory sound, the practice productive of large results. Cooperation is at once the greatest problem and the greatest opportunity of the human race.

To get the full significance of this statement it is necessary to go far back in history. Consider for a moment the origin and development of civilization. Man, as he emerged at the dawn of evolutionary history, was an extreme individualist. Each was for himself against all others. Gradually there developed leadership, first of the immediate family, then of the clan, then of the tribe, then of the nation. With each successively larger affiliation, the rights and powers of the individual became less and those of the group became greater. A part of the rights of the individual gave way to those of the family, a part of the rights of the family to those of the clan, some of those of the clan to those of the tribe, and some part of the rights and powers of the tribe to those of the nation. In our day, happily, some of the rights and powers of the nations gradually are giving way to the greater right and the greater power of humanity as a whole.

Cooperation means, literally, working together. It is evident that the development of civilization has been a development of the art of working together in larger and larger numbers for larger and larger purposes. This change has been progressing not only in the realm of government, but, as pointed out by C. R. Ball (7),[3] Barger (10), Butterfield (12), Cattell (14), Hughes (26), Livingston (34), Millikan (36), Wheeler (56), Whetzel (57), and others, it has been equally marked in the other major lines of human activity, namely, agriculture, education, religion (7, 12, 36), commerce, industry, and research.

Well known and almost universal instances of hurtful prejudice and antagonism may be cited, where friendly cooperation would have increased both pleasure and prosperity. Consider the ancient antagonism between "town and gown." This old ill feeling between the community and its college or university has given way to friendliness, appreciation, and cooperation for mutual advantage.

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Paper read before the joint meeting of the Society and Section O of the American Association for the Advancement of Science at Nashville, Tenn., Dec. 27, 1927.

[2]Principal Agronomist in Charge.

[3]Reference by number is to "Literature Cited," p. 1044.

Most of us have had personal experiences with the antagonism between the rural village or town and its surrounding farming community. Each is dependent on the other for its comfort and prosperity if not for its actual existence, yet this idea has gained painfully slow acceptance. In our present day the two are working together in larger and larger measure for the benefit of both.[4]

Consider also those long time antagonists, Capital and Labor. Capital seemed unable to see that an intelligent, prosperous, and contented workman was the best insurer of continuous profits. Labor seemed equally unable to see that strikes, with their resultant disruption of manufacture and frequent destruction of property, were as harmful to Labor as to Capital. In our new day the two slowly are learning that their interests are mutual and that they must work together for the common good.

In big business, where the most vicious competition formerly existed, there is a growing tendency to pool resources and allot fields, for greater mutual advantage. Not all their research is done behind closed doors, for their own exclusive benefit, but more and more are industrial fellowships and scholarships endowed for the benefit of the industry as a whole.

In the sphere of religious life the same tendency is strikingly apparent. Great communions, which separated, or arose independently, in an era of repression, are drawing closer together, or actually uniting, in this era of cooperation (7, pp. 1–2; 12).

Nowhere is this universal tendency more apparent to-day than in the art of agriculture. The cooperative movement was born some 40 years ago in resentment against the conditions then existing. It grew slowly at first, but in these modern days it is developing by leaps and bounds. A recent survey shows that agricultural cooperatives have doubled in numbers and quadrupled in volume of busines in the last 10 years.

Cooperation is the spirit of our age. It is anti-indifference, anti-exploitation, anti-prejudice, and anti-antagonism; in fact it is the very opposite of all anti-social ideas and movements. It is the growing spirit of friendliness. It is the universal ambassador of good will.

Science is international, cosmopolitan, universal— as suggested by E. D. Ball (9), Barger (10), Butterfield (12), Cattell (14), Hughes (26), Millikan (36), and Root (43). What more fitting than that it should lead in promoting cooperative enterprises of broad scope and large economic importance.

[4]See paper by the writer, entitled "The Merchant and Agriculture," to appear in the Yearbook of the North Dakota Retail Merchants' Association for 1928.

THE FOUR FACTORS IN RESEARCH

The four chief factors concerned in every piece of research have been defined by the writer (6) as (a) the problem, (b) the personnel, (c) the plan, and (d) the equipment. The elements of successful cooperation in research necessarily relate to all four of these, but principally to the first three, namely, problem, personnel, and plan.

The problem itself naturally is the most important of these factors because without the problem there would be no need for personnel or plan or equipment. At the same time it seems desirable to discuss first the elements relating to personnel. This is because the personnel recognizes the problem, develops the plan, and uses the equipment. The personnel also is the most personal, the most difficult, and the most permanent of the four factors named.

ELEMENTS OF COOPERATION IN THE PERSONNEL

The personnel that is concerned with cooperation in research includes two groups, the research staff and the administrative staff. These groups often are not sharply separated but both functions must be considered. Any given human characteristic will have about the same effect on cooperation if found in either group.

In this discussion we must assume the possession of those qualities which represent ability. They are imagination, initiative, and resourcefulness, which are the measures of the worker's ability to plan and to do or interpret new things, or old things in new and better ways. They include also energy, persistence, and judgment, which are the measures of his ability to overcome obstacles and to carry forward a piece of work steadily to its conclusion. These two groups are questions of ability. They are matters of the mind.

There are certain other qualities that are ethical in nature and therefore largely are matters of will. Among these are honesty, accuracy, and dependability, which are somewhat the measure of the worker's attitude toward himself in relation to his position. They include also inspirativeness, loyalty, and cooperativeness, which are the measures of the worker's attitude toward his associates and his organization. It is in these two groups of ethical characteristics that personnel elements of successful cooperation in research must lie. Of the six ethical attributes named, three are especially important in this consideration. They are mental honesty, inspirativeness, and cooperativeness. All of them have been considered at length by the writer (7) but time does not permit repetition here. Of these, cooperativeness is most important from the standpoint of the present discussion.

Cooperativeness is not a new and mysterious quality in personality. Its components are well-known and much-prized characteristics, such as vision, broadmindedness, desire for efficiency, responsibility, fairness, tolerance, unselfishness, and friendliness. Farrell (22), in a paper discussing the handling of research projects, advocated conferences and occasional lunches of the station staff as a means of promoting "acquaintance, good fellowship, *esprit de corps*, the research spirit, and a desire to be of service to the public." A better recipe or better results in developing the cooperative spirit scarcely could be devised.

There have been two rather comprehensive discussions of scientific personnel recently. In 1922, Brooks (11), who died not long after, wrote at length on "The Scientist in the Federal Service." In this paper he reviewed the development of research, the conditions under which Federal investigations are carried forward, the varying characteristics of scientific personnel, and the relation between the administrator and his staff.

The writer (6, 7) also has discussed the matter of personnel rather fully, from the standpoint of characteristics and their relation to research. In these papers it was pointed out that human personality is exceedingly variable. Mathematically, there are 4,096 possible combinations of the presence or absence of 12 characteristics. As each characteristic may be present in any one of many widely varying degrees of intensity, it is instantly apparent that personalities may and do vary in an infinite number of ways. Yet we are prone to look on a personality as a relatively fixed and stable quantity.

Many others have discussed various phases of the personnel problem. Only a few can be mentioned here. Among those who treat phases of the general problem of personnel are C. R. Ball (8), E. D. Ball (9, p. 195), Cattell (14), Cummings (17), Deming (20), Haskell (25), Irvine (27), O'Rourke (40), Pearson (41), Rosa (44), Seashore (45), Shear (46), Walcott (54), Wheeler (56), and Whetzel (57). Some who dwell particularly on rules for conduct, or codes of ethics, are Cunmmigs, et al (18), Deming (20, p. 76), and Thatcher, et al (49, 50).

ELEMENTS OF COOPERATION RELATED TO THE PROBLEM

The characteristics of a problem which make it most advantageously investigated through cooperation are (a) wide geographic distribution, (b) complex rather than simple nature, and (c) importance to all the proposed cooperating agencies. In fact, the three characteristics named essentially are one. The more widespread a problem is the more complex it is likely to be, and the greater the community

of interest of various agencies. For the purpose of this discussion it seems best to consider the problem as having this single element of widespread occurrence and interest.

It should be kept in mind that a problem existing only locally at a given time may have a very widespread significance, and therefore, be a proper subject for cooperative study. A newly introduced but very localized fungous disease or insect pest, having the possibility of extensive spread and destructiveness, would be an example of a local problem with wide significance. This was exactly the position of the corn borer problem several years ago.

What are the advantages which may result from a cooperative investigation of such widespread and important problems? This is a practical age, and, however much we cherish the ideal, it is necessary to live with the real. Are there sufficient advantages in cooperation to justify it in actual practice?

Before the convention of the Association of Land-Grant Colleges in 1921 the writer (5) presented a paper on the subject of "Federal and State Cooperation in Cereal Research." At that time eight definite advantages were recognized, of which six had been listed previously by other speakers before that body. In 1925, the writer (7) was invited to present a paper on "Some Elements of Successful Cooperation in Research" before the Special Conference of Directors of Agricultural Experiment Stations at St. Louis, where they had met to consider problems for investigation by funds to be appropriated under the Purnell Act. In that paper nine chief advantages of cooperation were presented. They are summarized here under the following heads:

1. Cooperation insures more comprehensive investigation.
2. Cooperation provides more unified methods and program.
3. Cooperation enables a better manning of the project.
4. Cooperation makes data promptly available to each worker.
5. Cooperation saves funds to each cooperating agency.
6. Cooperation conserves valuable material.
7. Cooperation obtains better publicity and support.
8. Cooperation stimulates the workers.
9. Cooperation begets cooperation.

1. MORE COMPREHENSIVE INVESTIGATION

Few important problems are confined within the limits of a single state or other investigating unit. When a state worker, however, begins research on a problem of wide distribution, he seldom has an opportunity to survey the entire problem in all its aspects before he begins work. This restriction may be due to concentration on the local phases of the problem, lack of funds, lack of approval for travel

outside his own state, or reluctance about entering the territory of other workers. Natural conditions often limit the trend of the investigation within a given state so that a comprehensive program can not be organized by one state alone.

Cooperation between adjacent states or groups of states, or between a state or group of states and a federal agency, automatically insures a better covering of the field. The problem is then seen in its entire perspective, and a comprehensive attack may be planned. Where two or more states undertake such a cooperating investigation, there must be successive conferences of the state workers. Where a federal agency enters the cooperation, it may serve as a coordinating agent and reduce the need and expense of frequent general conferences, although the intervisiting of the workers is highly necessary and profitable. Some good examples illustrating this advantage are the cooperative projects on corn root, stalk, and ear rots; barberry eradication; and winter hardiness of wheat.

Among the authors of recent papers before the meetings of station workers who state this to be one of the advantages of cooperation are Allen (2, 3), C. R. Ball (5), E. D. Ball (9), Coffey (15), Compton (16), Davenport (19), Drinkard (21), Farrell (22), Germann (23), Gray (24), Jardine (28), Kellogg (29), Kendall (30), Knight (31), Leake (32), Lipman (33), Livingston (34), Meredith (35), Mumford (38), Pearson (41), Ransom (42), Shear (46), Smith (47), Thatcher (48), Thorne (51), Trowbridge (52), Webber (55), and Whetzel (57).

2. STANDARDIZATION OF METHODS AND UNIFIED PROGRAM

The method of attack and the technic employed are likely to vary considerably in different groups of workers operating independently. Where two or more groups are associated the methods will be more similar and the results should be comparable. The best technic also will be available to all and economy of funds and more rapid progress are likely to result. This tends also to avoid criticism that otherwise might be directed against those less well equipped. The station workers who have recognized this as one of the advantages of cooperation are Drinkard (21), Gray (24), Lipman (33), Mumford (38), and Thatcher (48).

3. BETTER MANNING OF INVESTIGATION

When funds are made available for such an investigation, a portion goes toward salaries and another portion towards buildings and equipment. It frequently happens that buildings and equipment are in excess of needs of the personnel, at least at certain seasons of the year. Yet there is actual saving in providing buildings and equip-

ment for more than present needs. After that has been done there oftentimes is difficulty in maintaining sufficient personnel to utilize completely the space and equipment provided. Cooperation with another agency having free funds permits the better manning of the project and fuller use of the buildings and equipment already existing by providing sufficient personnel. Livingston (34) and Mumford (38) have recognized this advantage.

4. DATA MADE AVAILABLE TO EACH WORKER

Where different agencies are conducting independent investigations of the same problem, there usually is little sharing of the data obtained. This may be due to the fact that the agencies are in competition and that each is jealously guarding its own discoveries. It may mean that the leader of one of the researches is of the secretive type, and that nothing he has accomplished is given out until published, or it may mean simply that the two groups of workers are not in contact and hence there is no diffusion of results. Where this condition exists, from whatever cause, there is likely to be a waste of time, effort, and money.

One or another of the investigators is certain to make some advance in technic, or in interpretation of previous knowledge, or in discovery of new facts, which may make some change in alignment or procedure desirable. Those who are informed, and can make the necessary change, progress more rapidly thereafter. Those who are not so informed are handicapped. Research necessarily is slow, and the publication of results oftentimes is delayed long beyond the finding of isolated though important facts. Where cooperation exists, the findings become common property in carrying forward the work, and the credit goes to the finder, immediately in the appreciation of his associates, and eventually in the fuller report for publication. Thus the interest of the investigator and institution is safeguarded, and the whole investigation is benefited at once instead of tardily. Gray (24) and the writer (5) have referred to this advantage.

5. SAVING OF FUNDS TO INDIVIDUAL AGENCIES

Cooperation upon a problem of wide distribution relieves the individual states of the necessity of financing independent attacks on such a problem, or of leaving their constituencies unserved. Although under cooperation each institution must finance its own portion of the investigation, it need not finance a comprehensive attack on all phases of it. If the research on such a project were limited to what one state or unit could accomplish, progress would be much slower than is possible by making a combined attack. If

each state should undertake to solve the whole problem independently it would mean an unwarranted duplication of effort and expenditure, and a tying up of personnel and funds needed for other lines.

Where a state and federal agency cooperate, there is a great saving in the overhead for buildings, land, and equipment, as only one agency, usually the state, need provide these. This leaves more funds free for research personnel and avoids much duplication of stations. There may be a saving also in the funds otherwise expended for independent publications, and the cost of illustrations and publishing is no small item in station expense.

Station and federal workers who have recorded this as one of the obvious advantages are C. R. Ball (5), Coffey (15), Davenport (19), Drinkard (21), Germann (23), Gray (24), Kendall (30), Lipman (33), Mumford (38), and Webber (55).

6. CONSERVATION OF MATERIAL

In plant breeding operations a large quantity of hybrid material is produced at considerable labor and expense. Because of the varying adaptation of different plants and their progeny, as the writer (5) has previously pointed out, only a small part of the resulting material is likely to have characters adapting it to use in the locality where it is produced. Some of the remainder may have characters especially adapting it to other sections of the country, but, if it is being produced in one locality by a non-cooperating agency, all except that needed for home use will be discarded. With full cooperation between several states or with a federal agency as a coordinator, the material can be distributed to the sections where it is likely to be of value, with no loss to the originating agency, and with great possible gain to crop production as a whole.

7. BETTER PUBLICITY AND BETTER APPROPRIATIONS

Most research agencies are dependent on legislative bodies for their funds. Legislators can not be specialists in science, however honestly they may be trying to serve their constituencies to the best of their ability. They must depend largely on technical information and public sentiment in determining what causes to endow with sufficient funds. The very fact that an enterprise is cooperative tends to give it greater prestige. In accordance with the old saying that the prophet is not without honor save in his own country, the publicity and prestige arising from cooperation are likely to be helpful factors in obtaining appreciation and funds for each of the cooperating agencies.

Among the station and federal workers who have credited cooperation with bringing about these results are C. R. Ball (5), Drinkard (21), Gray (24), and Mumford (38).

8. STIMULATION OF THE WORKERS

There is a stimulation which comes from association with others. No station worker is isolated, so far as contacts with numerous other scientists are concerned, unless on a substation. He may be isolated, however, from much contact with other workers in his own particular field. If he is engaged in a cooperative problem with workers in other states, the mutual operations, meetings, and conferences are certain to prove stimulating. Knowledge and appreciation of the work are increased, interest quickened, and production enlarged. This tends to keep the worker more keen, more alert, in better spirits, and in all ways better equipped for his work. The writers previously cited who have recorded this as an advantage to be obtained by cooperation are C. R. Ball (5), Compton (16), Davenport (19), Drinkard (21), Farrell (22), Gray (24), Lipman (33), Mumford (37, 38), and Thatcher (48).

9. COOPERATION BEGETS COOPERATION

There is a saying that nothing succeeds like success. In other words, success sells itself. Cooperation has the same power. A little of it often is the leaven which gradually permeates the whole lump. As pointed out by the writer (5), Leake (31), and Shear (46), not infrequently the establishment of cooperation between two agencies has resulted in increased cooperation among the members of either agency, to the great advantage of their respective institutions. Cooperation is coming into its own.

COOPERATION IN CORN BORER RESEARCH

The corn borer research problem meets all the requirements previously stated for one justifying cooperative attack. It is of widespread distribution, of complex rather than simple nature, and of great public and professional interest to many and diverse groups of people. It is probable that there is no single problem in the control of insects or plant diseases which is of greater public importance, actual or potential, at the present time, than this same corn borer problem. It may well be that there never has been and never will be a single insect of more profound concern to as large an industry, or group of industries, and to as many people.

The literature which has developed in the past 10 years or so is most voluminous, as shown by the 914 American and European titles in the bibliography recently compiled by Wade (53), of which 330

had been added in the last three years. The size and complexity of the research program is well shown in the recent review by Caffrey and Worthley (13), while a similar perspective on the problems of quarantine and control is given in the companion publication by Worthley and Caffrey (58).

GEOGRAPHIC SCOPE OF THE PROBLEM

The corn borer is now an actual problem in the six New England states, New York, New Jersey, Pennsylvania, Ohio, Indiana, and Michigan, besides Ontario and Quebec in Canada. A limited infestation occurs also in the "panhandle" of West Virginia, between Pennsylvania and Ohio.

This insect is an acute problem of the immediate future to the remaining states of the whole Mississippi Valley, used in the broad sense as meaning the Mississippi drainage basin, and, in addition, to the remaining Atlantic Coast and cotton belt states outside this basin. This threatened area includes the remainder of our dairy belt, the corn belt, most of our wheat belt, and the cotton belt. The threatened plus the infested areas cover all the chief agricultural regions except the range region of the far West and include the chief cropping enterprises of our country.

The corn borer is a more remote problem in the western states of the Rocky Mountain, the Intermountain, and the Pacific Coast areas. Corn is but little grown in these states, it is true, although it is important in parts of Washington and California. Various grain sorghums, which may become severely attacked under the conditions prevailing, are important crops in the far Southwest, including Arizona and California. Cotton also is of tremendous importance in certain districts of the same area, and it likewise may prove susceptible to some injury.

The corn borer, therefore, is a potential problem of the first importance, affecting or likely to affect every state of the Union in view of the possible infestation of corn, sorghums, cotton, and hops, not to mention other valuable crop plants.

Certain economic considerations may be forced upon us in considering the geographic scope of this problem. The borer will not affect western Canada perceptibly, so far as now appears, because corn is not an important crop there. As the borer spreads westward into the increasing corn fields of our upper Mississippi basin, however, it will still further increase the present handicap of our western farmers in competing with their Canadian brothers. In the cotton belt, if the corn borer be added to the boll weevil as an additional

enemy of cotton and a prime enemy of corn, it conceivably may further handicap our farmers there in growing cotton in competition with other cotton-producing areas, whether in our southern Great Plains area and Pacific Southwest, or in the countries of South America, Africa, or Asia.

COMPLEXITY OF THE PROBLEM

The corn borer problem is tremendously complex from the standpoints of (a) the enormous and diverse geographic area involved, (b) the large and varied series of climatic conditions prevailing in this area, (c) the extensive and diverse soil types which occupy it, (d) the diversity of the crop plants which are or may become infested, (e) the numerous and important commercial industries directly or indirectly affected, and (f) the uncertainties regarding the economic effects which the spread and increase of the European corn borer will produce.

In its actual complexity, and in its economic implications, the corn borer problem interests enormous numbers of persons. It also compels the professional attention of many widely different groups of scientists. Among those whose researches have been or yet must be brought to bear upon the problem, are the following, alphabetically arranged: (a) agricultural engineers, (b) agronomists, (c) animal husbandmen, (d) chemists, (e) control officials, (f) dairymen, (g) ecologists, (h) economists, (i) entomologists, (j) extensionists, (k) geneticists, (l) horticulturists, (m) plant physiologists, and (n) soil scientists, not to mention administrators or publicity experts.

It goes without saying that the problem, as seen from the viewpoint of any one of these groups, is more or less closely related to the problem as seen by any or all of the other groups. Only by a careful correlation of the lines of attack can it be insured that parts of the problem are not left untouched and that work on other parts is not duplicated unnecessarily.

ADVANTAGES OF COOPERATION

With a problem so widespread and so complex there is large opportunity for cooperation in the attack upon it. There would seem to be an even greater obligation to the fullest cooperation possible. Numerous federal and state research agencies already are engaged upon it. Many committees and other representatives of institutions and organizations are preparing research programs covering it. There already is a fine volume of cooperative attack, some of it by associated states, some by federal and state agencies. These cooperations can be greatly enlarged. Without coordination and cooper-

ation there will be unnecessary and wasteful duplication at many points and a failure to cover the field at other points.

Without question, every one of the nine advantages recognized as resulting from cooperation would be realized in such a cooperative attack on this problem.

Increasing approval has been given to large-scale cooperation in scientific research by federal and state officials and organizations, as quoted by the writer (7, pp. 24–40). Allen (1) has summarized the whole status of cooperation between federal and state agencies. The number, size, and scope of the projects in agriculture were most gratifying. His report was discussed editorially in Science (4). Other important papers on cooperation between state experiment stations, or federal and state units, are by Allen (2, 3), E. D. Ball (9), Coffey (15), Davenport (19), Drinkard (21), Gray (24), Jardine (28), Kendall (30), Knight (31), Lipman (33), Meredith (35), Mumford (37, 38, 39, the latter paper quoting the principles of cooperation as stated by the Secretary of Agriculture), Thatcher (48), Thorne (51), Trowbridge (52), and Webber (55).

The soil for cooperative research is fertile and mellow. Splendid cooperation in corn borer research already is under way. Still more is desirable and will be profitable. The opportunity waits. Given such an enormous problem, the urgent necessity for continued prompt and effective action, a public and official sentiment favorable to cooperative research, and large funds available for the work, we may look confidently for the most gigantic single cooperative enterprise yet undertaken.

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EFFECT OF FERTILIZERS ON THE SIZE OF COTTON BOLLS[1]

R. P. BARTHOLOMEW AND GEORGE JANSSEN[2]

Fertilization of cotton soils has become a common practice in the United States. Such a practice is warranted because of the increased profit obtained through fertilization. Manifestly where so great attention is devoted to the maintenance and increasing of yields, through the use of commercial fertilizers, the yielding power of the plant is of primary importance to the farmer and it has been a criterion upon which the value of the fertilizer has been based.

It is apparent from a survey of the literature on fertilizer experiments with cotton that the majority of emphasis is placed on the total yield of lint or seed cotton per acre. Whether the increased yields are the result of larger plant growth, together with a greater number of bolls per plant, resulting from the fertilizer application or whether they are due to the production of larger bolls or to a combination of the two factors is not clear.

In 1927, in connection with a number of fertilizer experiments located in different parts of Arkansas, a study of growth characters was made which had for its object, first, to determine the effect of fertilizers on the size of cotton bolls and, second, to determine the effect of fertilizers upon the percentage of lint per boll.

The literature pertaining to the objects of this experiment is very meager. Newman,[3] working in Alabama, has shown that the weight per boll in ounces may vary with the kind of fertilizer applied, the amount applied, and the type of soil to which it is applied. He used ammonium sulfate, superphosphate (acid phosphate), and cottonseed hull ashes separately and in combinations. While his results fluctuated with different types of soil, in the majority of cases, the application of fertilizers stimulated heavier boll development.

EXPERIMENTAL

The experiments were conducted on tenth acre plats under the supervision of county agents of the counties in which the experiments were located and were visited by members of the Department of Agronomy. The treatments used were (1) sodium nitrate, 150 pounds

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[3]NEWMAN, J. S. Cotton. Ala. Agr. Exp. Sta. Bul. 5: 1-28. 1889.

and superphosphate (acid phosphate), 250 pounds; (2) superphosphate (acid phosphate), 250 pounds, and muriate of potash, 30 pounds; (3) sodium nitrate, 150 pounds, and muriate of potash, 30 pounds; (4) sodium nitrate, 150 pounds, superphosphate (acid phosphate), 250 pounds, and kainite, 100 pounds; (5) sodium nitrate, 150 pounds, superphosphate (acid phosphate), 250 pounds, and muriate of potash, 30 pounds; and (6) sodium nitrate, 150 pounds, superphosphate (acid phosphate), 250 pounds, and muriate of potash, 60 pounds.

Most of the soils were of a sandy nature varying from fine sands to sandy loams and loams. The variety of cotton used depended upon the farmer's preference. Fifty bolls free from weevil injury and disease were saved from the first picking in order that the percentage of lint and weight of boll could be determined. The results are given in Table 1.

While it is realized that the results from a single year's fertilizer experiments may be misleading, the fact that the experiments were made in many sections of the state and with several varieties of cotton should make them significant. Moreover, the study was limited to the size of the cotton bolls and the total yields were only used to demonstrate the manner in which increased yields occurred when fertilizers are applied to soils.

A study of the results shows that the fertilizers may operate in two ways exclusive of increasing the number of bolls per acre. No boll counts were made, but the approximate number can be obtained by dividing the total weight of seed cotton per acre by the weight of seed cotton per boll. (See Table 2.)

In nearly all trials the fertilizer increased the weight of the bolls. Small variations of a few per cent may be due to experimental error, but differences greater than 10% should be significant. The increases in weight of bolls varied from almost nothing up to 105.6%. It is also evident that besides increasing the weight of the bolls the fertilizers may increase the percentage of lint per boll. The increases in percentage of lint are not as general as those of the weight of boll nor are they as large. However, there is a sufficient number taken from many varied conditions to establish the fact that such an effect may take place.

All the cotton which opened before the first killing frost was picked in several pickings and the weights taken. The total weights are found in Table 2.

The results show that in all cases the soils responded to fertilizers. Where the proper fertilizers were applied the increases were very

TABLE 1.—*Weight and percentage of lint of 100 bolls from cotton grown with the fertilizer treatments indicated.*

Location	Fertilizer treatment*	Variety	100 bolls					
			Weight of seed cotton, pounds	Increase yield seed %	Weight of seed, pounds	Weight of lint, pounds	Percentage of lint	Length of staple, mm
Clarksville	Check†	Half and Half	0.71	—	0.43	0.28	39.5	23
	N P		1.46	105.6	0.92	0.54	37.0	23
	P K		0.76	7.0	0.44	0.32	42.2	24
	N K		1.00	40.8	0.62	0.38	38.0	22
	N P Kainite		1.30	83.1	0.84	0.46	35 0	24
	N P 1 K		1.30	83.1	0.84	0.46	35.4	26
	N P 2 K		1.32	84.5	0.86	0.46	34.8	24
Walnut Ridge	Check	Watson's Wilt Resistant	1.38	—	0.91	0.47	34.1	26
	N P		1.36	—	0 88	0.48	35.3	25
	P K		1.56	13.0	1.00	0.56	35.9	26
	N K		1.56	13.0	0.96	0.60	38.4	24
	N P Kainite		1.62	17.4	1.02	0.60	37.0	24
	N P 1 K		1.42	2.9	0.92	0.50	35.2	25
	N P 2 K		1.56	13.0	1.00	0.56	35.9	24
Prescott	Check	Delfos	1.29	—	0.90	0.37	28.6	30
	N P		1.32	2.3	0.92	0.40	30.3	31
	P K		1.38	7.0	0.98	0.40	29.0	31
	N K		1.38	7.0	1.00	0.38	27.5	31
	N P Kainite		1.28	—	0.90	0.38	29.7	31
	N P 1 K		1.42	10.0	1.00	0.42	29.5	31
	N P 2 K		1.46	13.2	1.02	0.44	30.1	30
Hampton	Check	Half and Half	1.57	—	1.04	0.53	33.8	26
	N P		1.76	12.1	1.16	0.60	34.1	26
	P K		1.70	8.3	1.08	0.62	36.4	27
	N K		1.86	18.5	1.20	0.66	35.5	24
	N P Kainite		1.58	0.6	1.02	0.56	35.4	26
	N P 1 K		1.60	1.9	1.02	0.58	36.2	26
	N P 2 K		1.66	5.7	1.02	0.64	38.5	25

Sheridan	Check	Rowden	1.36	——	0.91	0.45	33.1	26
	N P		1.70	25.0	1.10	0.60	35.3	25
	P K		1.52	11.7	1.02	0.50	32.9	25
	N K		1.54	13.2	1.02	0.52	33.7	25
	N P Kainite		1.54	13.2	1.00	0.54	35.0	25
	N P 1 K		1.54	13.2	1.00	0.54	35.0	27
	N P 2 K		1.56	14.7	1.02	0.54	34.6	26
Hope	Check	Rowden	1.43	——	0.96	0.47	32.8	28
	N P		1.40	——	0.94	0.46	32.8	29
	P K		1.42	——	0.92	0.50	35.2	28
	N K		1.46	2.1	0.96	0.50	34.2	29
	N P Kainite		1.62	13.3	1.06	0.56	34.6	29
	N P 1 K		1.64	14.7	1.08	0.56	34.1	27
	N P 2 K		1.74	21.6	1.16	0.58	33.3	29
Leachville	Check	Acala	1.06	——	0.70	0.36	34.0	30
	N P		1.42	34.0	0.96	0.48	33.8	30
	P K		1.40	32.1	0.94	0.46	32.8	31
	N K		1.42	34.0	0.96	0.46	32.4	31
	N P Kainite		1.38	30.2	0.92	0.46	33.3	32
	N P 1 K		1.02	——	0.66	0.36	35.3	30
	N P 2 K		1 46	37 7	0.98	0.48	32.9	31
Earle	Check	Delfos	0.77‡	——	0.40‡	0.37‡	48.1	31
	N P		0.81	5.2	0.41	0.40	49.5	32
	P K		0.65	——	0.32	0.33	50.8	32
	N K		1.00	30.0	0.51	0.49	49.0	30
	N P Kainite		0.80	3.9	0.38	0.42	52.5	30
	N P 1 K		0.75	——	0.38	0.37	49.4	29
	N P 2 K		0.92	19.5	0.48	0.44	47.9	30
Fayetteville	Check	Delfos	1.10	——	0.79	0.31	28.2	32
	N P		1.29	17.3	0.94	0.35	27.1	32
	N P 100 K		1.39	26.4	0.96	0.48	34.5	31
	N P 300 K		1.22	10.9	0.90	0.32	26.2	31
	N P 450 K		1.36	23.6	0.95	0.41	30.1	33

*Symbols indicate as follows: N = NH_3, P = P_2O_5, and K = K_2O.
†Check plats are average of three plats.
‡Weights for the experiment at Earle calculated on 10-boll samples.

TABLE 2.—*Total yield of seed cotton and number of bolls per acre with fertilizer treatments indicated.*

Location	Fertilizer treatment*	Variety	Total yield seed cotton per acre, pounds	Increase yield seed cotton %	Total number of bolls per acre	Increase in number of bolls per acre %
Clarksville	Check†	Half and Half	4‡	——	——	——
	N P		90	——	——	——
	P K		4.3	——	——	——
	N K		20	——	——	——
	N P Kainite		75	——	——	——
	N P 1 K		80	——	——	——
	N P 2 K		——	——	——	——
Walnut Ridge	Check	Watson's Wilt	890	——	64,240	——
	N P	Resistent	1,070	20.2	78,750	22.6
	P K		980	10.1	62,800	——
	N K		1,380	55.0	87,040	37.1
	N P Kainite		1,730	94.4	106,800	66.2
	N P 1 K		1,480	66.3	104,200	62.2
	N P 2 K		1,280	43.8	82,060	34.0
Prescott	Check	Delfos	912	——	70,640	——
	N P		1,175	28.8	89,000	26.0
	P K		955	4.7	69,150	——
	N K		1,050	16.2	76,120	7.8
	N P Kainite		1,210	32.7	93,890	32.9
	N P 1 K		1,225	34.3	86,300	22.5
	N P 2 K		1,200	31.6	82,160	16.3
Sheridan	Check	Rowden	507	——	37,280	——
	N P		910	78.4	53,500	43.5
	P K		740	45.3	48,700	30.7
	N K		640	25.9	41,530	11.4
	N P Kainite		490	——	31,800	——
	N P 1 K		570	12.2	37,000	——
	N P 2 K		510	0.6	32,700	——
Hope	Check	Rowden	458	——	32,000	——
	N P		626	36.5	44,700	39.7
	P K		451	——	31,750	——
	N K		587	28.2	40,200	24.3
	N P Kainite		862	88.2	53,100	66.0
	N P 1 K		1,041	127.2	63,530	98.6
	N P 2 K		1,045	128.5	60,080	87.7
Earle	Check	Delfos	985	——	——	——
	N P		1,130	14.9	——	——
	P K		1,160	17.8	——	——
	N K		1,080	9.6	——	——
	N P Kainite		830	——	——	——
	N P 1 K		1,270	18.9	——	——
	N P 2 K		1,360	38.1	——	——

*Symbols indicate as follows: N = NH_3, P = P_2O_5, and K = K_2O.

†Check plats are average of three plats.

profitable even when the check plats produced as much as 900 pounds of seed cotton per acre. The fertilizer giving the best results varied, depending on the soil type and its previous treatment.

DISCUSSION OF THE RESULTS

A better insight into the manner in which fertilizers increase the yield of cotton can probably be obtained by studying collectively the effect of fertilizers on the total yield of seed cotton, the number of bolls per acre, the size of the bolls, and the percentage of lint per boll. These data from several of the experiments have been compiled in Table 3.

TABLE 3.—*Increase in size of boll, percentage of lint, number of bolls per acre, and total yield of seed cotton per acre in field experiments with fertilizer treatment indicated.*

Location	Fertilizer treatment*	Variety	Increase in total yield seed cotton %	Increase in number of bolls per acre %	Increase in size of boll %	Increase in percentage of lint per boll
Walnut Ridge	Check†	Watson's Wilt	——	——	——	——
	N P	Resistent	20.2	22.6	——	3.5
	P K		10.1	——	13.0	5.3
	N K		55.0	37.1	13.0	12.6
	N P Kainite		94.4	66.2	17.4	8.5
	N P 1 K		66.3	62.2	2.9	3.2
	N P 2 K		43.8	34.0	13.0	5.3
Prescott	Check	Delfos	——	——	——	——
	N P		28.8	26.0	2.3	6.7
	P K		4.7	——	7.0	1.4
	N K		16.2	7.8	7.0	——
	N P Kainite		32.7	32.9	——	3.8
	N P 1 K		34.3	22.5	10.0	3.1
	N P 2 K		31.6	16.3	13.2	5.2
Sheridan	Check	Rowden	——	——	——	——
	N P		78.4	43.5	25.0	6.7
	P K		45.3	30.7	11.7	——
	N K		25.9	11.4	13.2	1.8
	N P Kainite		——	——	13.2	5.7
	N P 1 K		12.2	——	13.2	5.7
	N P 2 K		0.6	——	14.7	4.5
Hope	Check	Rowden	——	——	——	——
	N P		36.5	39.7	——	——
	P K		——	——	——	——
	N K		28.2	24.3	2.1	7.3
	N P Kainite		88.2	66.0	13.3	4.3
	N P 1 K		127.2	98.6	14.7	5.5
	N P 2 K		128.5	87.7	21.6	1.5

*Symbols indicate as follows: N = NH_3, P = P_2O_5, and K = K_2O.
†Check plats are average of three plats.

The results of the experiment demonstrate the various ways in which fertilizers may produce increased yields. For example in the N P treatment there was an increase of 20% in total yield of seed cotton. This increase is probably due largely to the 22.6% increase in number of bolls per acre as there was a slight decrease in the size of the bolls and only a small increase in the percentage of lint.

The P K treatment furnishes a second example. In this case there was a 10% increase in total yield of seed cotton accompanied by a decrease in number of bolls per acre. At the same time there was a 13% increase in size of the bolls and a 5.3% increase in the percentage of lint. The increase in this case was probably due to the increase in size of bolls and the percentage of lint.

The N K, N P Kainite, and N P 2 K treatments indicate a third manner in which yields may be increased. In these cases there is an increased yield of seed cotton accompanied by a much smaller increase in the number of bolls per acre. At the same time there is a substantial increase in the weight of the bolls and percentage of lint per boll. The increased yield in these cases was probably due to all three factors.

CONCLUSION

The results of these experiments show that fertilizers may function in several ways in order to increase yields of cotton. The fertilizer may increase yields of cotton (1) by increasing the number of bolls per acre, (2) by increasing the number and size of bolls, and (3) by increasing the size of bolls and the percentage of lint per boll.

THE PREVALENCE OF MIXTURES IN MARQUIS WHEAT GROWN IN CENTRAL MONTANA IN 1926[1]

Karl S. Quisenberry, J. Allen Clark, and B. B. Bayles[2]

For the past 12 years Marquis has been the variety of hard red spring wheat most commonly grown in Montana. Since its introduction in 1913 it has steadily increased in acreage. In 1919 about 40% of the total wheat acreage of Montana was estimated to be Marquis, and by 1924 it occupied about 72% of the total acreage (2).[3]

The Marquis variety has short kernels which are easily identified, and the awnletted spikes and white glabrous glumes make identification in the field rather simple. Marquis now is grown in many sections to the exclusion of all other varieties, and it would seem that the variety as grown on Montana farms should be true to type and relatively free from mixtures. In recent years seed associations have been inspecting and certifying pure seed of the variety, which also should tend to keep the variety pure.

MARQUIS WHEAT MIXTURES

In spite of the factors tending toward varietal purity, it has been known that mixtures of various sorts are present in Marquis as grown in Montana, in other states, and in Canada. Bell and Cartter (1) have studied plants grown from white kernels obtained in commercial samples of Montana-grown Marquis. They concluded that these white kernels were due to mechanical mixtures and possibly some natural crossing.

Harrington (3) conducted an extensive investigation on 15 collections of Marquis wheat from various sources in Canada. Some of these samples were from pure-line selections grown experimentally, while others were from commercial fields. Nine of these samples proved to be typical Marquis, while six were not typical. One of the non-typical strains, which is widely grown in Saskatchewan, was given special study. The plants of this lot were divided as non-Marquis, Marquis, and an intermediate type, and further tested in

[1]Contribution from Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Paper read at the meeting of the Western Section of the American Society of Agronomy held at Davis, Calif., June 19 to 21, 1928. Received for publication July 2, 1928.

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[3]Reference by number is to "Literature Cited," p. 1063.

progeny rows. In all cases the non-Marquis and Marquis types bred true, while the intermediate group did not breed true in all cases, a few of both Marquis and non-Marquis types being recovered. It was concluded that the intermediate type possibly was the result of natural crossing.

Newman (5) has reported on a study of commercial Marquis stocks collected in Manitoba and Saskatchewan. Samples consisting of about 50 heads each were obtained from 167 growers. It was found that 61% of these samples were not Marquis, 29% were definitely Marquis, and 10% were tentatively identified as Marquis pending further study. The off types were classed into eight groups, which appeared regularly and could be described. Various types which could not be placed in any one of the eight definite groups were placed in a "miscellaneous" group. By growing and studying the progeny, it was found that in general the definite groups tended to breed true. The "miscellaneous" group, however, broke up. It is suggested that this behavior indicates that natural crossing had taken place. This view is further supported by the discovery that those strains from a given source which were free or relatively free from other recognized types were singularly free from these "miscellaneous" types. In other words, the purer the variety the fewer were the chances for new forms to arise through natural crossing.

The writers have made additional studies to determine the prevalence and nature of mixtures found in Marquis wheat in Montana.

MATERIALS AND METHODS

During the summer of 1926 the Office of Cereal Crops and Diseases, in cooperation with the Divisions of Farm Management and Costs and Agricultural Engineering, United States Department of Agriculture, and with the Montana Agricultural Experiment Station, conducted investigations on the efficiency of the combine or combined harvester thresher. This study was conducted in Judith Basin, Fergus, and Hill Counties, in Montana. From each field studied a sample of wheat heads was obtained and forwarded to Washington, D. C. While inspecting the grain samples, after threshing, it was noticed that many samples contained white kernels. From each of these samples the white kernels were picked for growing in 1927. From the same sample 70 red kernels were taken at random for growing in comparison with the white. All the material was space planted in rod rows, 70 kernels per row, at Moccasin, Mont., in 1927. It was thought that in this way it would be possible to

identify the white-kerneled strains found as well as to determine the percentage of mixtures, not only from white-kerneled strains but also from red-kerneled strains.

At harvest all the heads from each plant grown from a white kernel were harvested and placed in separate envelopes. From the red-kerneled rows a single head from each plant in the row was harvested and all placed in one envelope. This material was sent to Washington, D. C., for study. In a few cases the white-kerneled material was injured before the heads were harvested, causing complete loss of some of the material, or a reduction in the number of heads available for study. In studying the material an attempt was made to identify each of the plants by the spike or kernel characters. If identification was impossible the descriptions of the spike characters were recorded and the strain was reported as unidentified.

PREVALENCE OF MIXTURES

A total of 102 samples from fields of spring wheat in Judith Basin, Fergus, and Hill Counties was studied. Of this number, 79, or 77.5%, showed white kernels. The percentage of white kernels ranged from a trace to 3.3, while the average for 77 samples (2 samples which later proved to be predominately winter wheat excluded) was 0.6%. These figures are based on kernel counts made on 1,000 kernels of the original samples.

Red kernels, taken at random from each of these 79 samples showing white kernels, were grown to identify any red-kerneled mixtures which might be present. Of the 79 samples grown 2 samples proved to be chiefly winter wheats and are not included in these calculations. Of the remaining 77 samples showing white mixtures, 68 showed red-kerneled mixtures ranging from 1.4 to 35.9% with an average of 8.8%.

Combining the white and the red-kerneled mixtures as found both in the original field samples and from growing the material in the nursery, it is found that for the 77 samples the percentage of mixtures ranged from a trace to 36.5% with an average of 9.4%.

IDENTIFICATION OF MIXTURES

Both the white and red-kerneled mixtures in the Marquis samples were studied for identification.

WHITE-KERNELED MIXTURES

From each sample of Marquis wheat containing white kernels the white kernels were saved and grown separately for identification. A total of 67 samples was grown to maturity and studied. As far as

possible, each plant was identified, but if there was no known variety showing similar characteristics only the description of the spike and kernel was recorded. A summary of the identifications is given in Table 1.

TABLE 1.—*Identification of plants grown from white kernels picked out of 67 Marquis wheat samples from Montana.*

Varieties or strains	Samples showing mixtures		Average percentage of white mixture
	Number	%	
Identified varieties:			
Pacific Bluestem	10	14.9	15.9
Little Club	7	10.4	34.0
Hard Federation	3	4.5	6.1
Big Club	2	3.0	3.4
Federation	2	3.0	25.2
Galgalos	1	1.5	50.0
Red Chaff (club)	1	1.5	3.4
Baart	1	1.5	2.4
Dicklow	1	1.5	33.3
Kubanka	1	1.5	8.9
Unidentified strains:			
"Like Marquis—White"	54	80.6	48.1
Awnless, glabrous, white glumed, white kerneled	48	71.6	39.0
Awnless, glabrous, brown glumed, white kerneled	25	37.3	24.1
Bearded, glabrous, white glumed, white kerneled	12	17.9	20.2
Bearded, glabrous, brown glumed, white kerneled	5	7.5	20.6
Winter type	3	4.5	2.3
Bearded, glabrous, white glumed, white kerneled (club)	2	3.0	44.6
Awnless, pubescent, brown glumed, white kerneled	2	3.0	22.1

The number and percentage of fields containing each identified variety and described type are shown, as well as the proportion of the total white mixture that was represented by the variety in the samples where it occurred. Of the identified varieties Pacific Bluestem occurred in 10, or 14.9%, of the samples. In these 10 samples an average of 15.9% of the total white mixture was Pacific Bluestem. In all, 10 known varieties were identified, each occurring in from 1 to 10 samples and in varying degrees of mixture.

The greater number of the white-kerneled mixtures could not be identified. The type most frequently recovered was very similar to Marquis in spike and kernel characters except that the kernel color

was white. This type was termed "Like Marquis—White," and was present in 80.6% of the white samples to the extent of 48.1% of the white mixture. Next in frequency were awnless, glabrous, white-glumed, white-kerneled types that were not typically Marquis. A total of eight unidentified botanical types was described, which made up the greater bulk of the white-kerneled plants. Both bearded and awnless, white and brown-glumed types were obtained. In three samples winter-type plants were found. It was impossible to identify these types because they failed to head. In all, 18 different varieties or botanical types were found among the plants grown from white kernels.

RED-KERNELED MIXTURES

Random samples of red kernels from 79 Marquis fields showing white mixtures were grown to determine the possible red mixtures present. From these red-kerneled samples, 14 distinct red-kerneled types and 1 white-kerneled type were recognized, as shown in Table 2. Of this number, nine were named varieties and six were unidentified botanical types. All but two of the samples proved to be predominately spring type.

TABLE 2.—*Identification of plants grown from random samples of red kernels taken from 77 Marquis wheat fields in Montana.*

Varieties or strains	Samples showing mixtures		Average percentage of red mixture
	Number	%	
Identified varieties:			
Ladoga	56	72.7	7.1
Stanley	24	31.2	2.9
Kota	8	10.4	3.3
Preston	5	6.5	3.1
Haynes Bluestem	3	3.9	3.2
Red Bobs	2	2.6	8.8
Huron	2	2.6	4.5
Prelude	1	1.3	2.3
Kitchener	1	1.3	18.0
Unidentified strains:			
Bearded, white glumed, red kerneled	11	14.3	2.6
Winter type	8	10.4	4.3
Bearded, brown glumed, red kerneled	4	5.2	2.0
Awnless, white glumed, red kerneled	3	3.9	3.3
Awnless, white glumed, white kerneled	2	2.6	2.2
Bearded, brown glumed, red kerneled (club)	2	2.6	1.9

The most frequently occurring red-kerneled mixture was Ladoga, a bearded brown-glumed variety. Ladoga was present in 56 of the 77

samples to the average extent of 7.1% of the red-kerneled plants. This shows that Ladoga is the most common mixture in Marquis wheat. The next most frequent mixture was Stanley, an awnless, brown-glumed variety, which was found in 24 samples, or 31.2%. Ladoga was distributed to farmers in northwestern Canada from 1888 to 1893 by the Canadian Department of Agriculture to provide a wheat ripening about 10 days earlier than Red Fife. Stanley originated about 1895 from a Ladoga x Red Fife cross, it being of the same parentage as Preston. Both were distributed for commercial growing by the Canadian Department of Agriculture in the late eighties. This evidently accounts for the presence of these varieties in Marquis fields.

In the red-kerneled samples unidentified strains were not so numerous as in the white-kerneled samples. Both bearded and awnless, white- and brown-glumed sorts were obtained, the most common being a bearded, white-glumed, red-kerneled type.

It is of considerable interest to note that in two cases awnless, white-glumed types with white kernels were obtained from red-kerneled samples. It is probable that these were grown from red kernels which were hybrids heterozygous for kernel color.

In eight samples, winter type plants which failed to head were observed. Two of the samples grown gave more winter types than spring. One sample had 87.2% and the other 69.1% winter. These two samples are not included in the averages. This extreme case of mixing was caused by the fact that winter wheat, sown in the fall, winterkilled badly. Spring wheat was then sown in the field without destroying what was left of the winter wheat.

ORIGIN OF MIXTURES

The data presented clearly show that mixtures in Marquis spring wheat are not at all uncommon. Both white- and red-kerneled mixtures were found in samples from central Montana. Some seed stocks were found which were true to type, but at least 77% of the samples showed some mixtures.

The question arises as to the origin of these mixtures. Since so many recognized varieties were found, it is evident that mechanical mixing was the principal cause. This would explain the presence of the recognized varieties, but not the unidentified types. These may be accounted for in part by assuming natural crossing between Marquis and the mixed varieties present.

Among the white-kerneled mixtures the most common type found was an awnletted, white-glumed, white-kerneled wheat much like Marquis and termed "Like Marquis—White." The definite proof of

the cause for the occurrence of this type would be of considerable interest. There are various ways in which this type could arise. Occurring in such relatively large numbers and having the spike and kernel characters of Marquis, differing only in kernel color, might suggest natural crossing between different lines of Marquis. For this to occur it would be necessary for Marquis to have at least two different genetic factors for red kernel color, some plants lacking one of these factors and some the other. If some strains were of the genotype RRr'r' and others rrR'R', natural crossing followed by segregation would result in some white-kerneled strains having the genotype rrr'r'. So far there is no direct evidence to support such a theory.

It has been shown by Hayes and Robertson (4) that in Minturki x Marquis and Kanred x Marquis crosses white-kerneled strains are obtained. It is rather common practice in Montana to seed winter wheat in the fall, and if winterkilling is severe, to reseed with Marquis in the spring. Two of the samples grown showed this condition. The winter wheat in most cases is not all destroyed and some natural crossing could take place. So far as is known no Minturki wheat is raised in Montana, but Kanred is grown and it is highly probable that the same results also could be obtained with Turkey, Kharkof, or Karmont, which are widely grown.

Various white-kerneled strains were present in the Marquis wheat mixtures. By natural crossing between Marquis and other white-kerneled varieties present as mechanical mixtures, white-kerneled strains, with spike and kernel characters similar to Marquis, could be developed. The presence of various combinations of awn development and glume color would indicate that such crossing, followed by segregation, had taken place. This does not entirely explain, however, why the majority of the white mixtures should be awnless, white-glumed, white-kerneled strains which closely approach Marquis in all characters except kernel color.

PURE SEED DESIRED

The facts herein reported show the need of careful seed selection. So far the extent of mixing has not become great enough to cause dockage on the market, but if allowed to continue would probably do so. Not all varieties are equally productive, and if Marquis continues to become mixed with inferior varieties the yield will be reduced. The condition pointed out in this paper is significant in that Marquis is the principal spring wheat grown in Montana. Few, if any, white wheats have ever been grown in this area, yet white kernel types appear in Marquis. Seed inspection should become

more general and more strict, and farmers should be encouraged to obtain good pure seed and to keep it pure. The advent of the small combine, permitting many farmers to own their own machines, should make it easier to keep seed supplies purer than when larger combines or stationary threshers moved from farm to farm.

SUMMARY

1. Samples of Marquis wheat were obtained from 102 fields in central Montana and 79, or 77.5%, showed white kernels. In the 77 samples which proved to be chiefly spring wheat, 0.6% of the kernels were white.

2. Random samples of red kernels were taken from these same fields and when grown showed an average mixture of 8.8%, making a total mixture of 9.4% for the samples studied.

3. When the white kernels picked from the 79 samples were grown, 18 different types were obtained of which 10 were identified as standard varieties. The majority of the white-kerneled mixture was an awnletted, glabrous, white-glumed sort, white kerneled, but otherwise like Marquis.

4. Plants grown from random samples of red kernels taken from the 79 samples containing the white mixtures, produced 15 distinct types. Of these, nine were identified as standard varieties, Ladoga being the most common. Winter types were found among the plants grown from red kernels. In two samples there were more winter than spring types.

5. The origin of the unidentified sorts is of interest, but definite proof as to their origin is not available. They could arise through natural crossing between Marquis and the varieties occurring as mixtures.

6. The white-kerneled strains which are similar to Marquis may arise by natural crossing between strains of Marquis, by crossing between Marquis and Kanred, Turkey, or Kharkof, or by crossing Marquis with some of the white-kerneled mixtures present. The last explanation seems at present to be the most logical. There is no direct evidence in favor of the first suggestion. For many of the observed cases the last suggestion is the most probable, but it does not explain the preponderance of white-kerneled sorts otherwise similar to Marquis.

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LOCATION OF "MOTES" IN THE UPLAND COTTON LOCK[1]

H. E. Rea[2]

Mature locks of upland cotton often contain aborted ovules which commercial ginners commonly call "motes." Fig. 1 (A) presents one of these motes in comparison with a normal ovule at the time of fertilization, together with mature sound seed, ginned and unginned. Fig. 1 (B) compares a perfect lock with a lock in which all the seed are aborted.

The cotton plant is ordinarily thought to be an efficient producer of sound seed, but recent work would indicate that such is not the case. In 1925 records on Durango cotton show that 47.4 ± .78% of all the ovules formed produced motes. Of the 16 varieties studied in 1925, Anton was found to produce the lowest percentage of motes, however 22.3 ± 1.02% of its seed were aborted. The highest count recorded on the same group of varieties grown in 1926 was for Snowflake, with 23.9 ± .61% of motes, and the lowest was Sunshine with 14.7 ± .46%.

A knowledge of the location of these motes in the individual cotton lock might suggest some of the factors involved in their occurrence. A typical upland cotton lock has nine seeds, *viz.*, one at the apex and four pairs of seed from the apex to the base of the lock. In this work each seed in a typical lock was given a number by which to indicate the motes. The arrangement of these numbers is illustrated in the perfect lock of Fig. 1 (B).

In 1924, 10 consecutive cotton plants were taken at random from a population of 411 Anton field selections as a preliminary sample for the study of mote location. Table 1 tabulates the results of this study. The first column gives a typical cotton lock with the location of each seed numbered. In the other columns the total number of seed examined, the total number of motes, and the percentage of motes to all seed in each location from the top to the bottom of the lock are recorded consecutively.

TABLE 1.—*Location of motes in 10 plants of Anton cotton, 1924.*

Location	Total seed	Total motes	Percentage motes
(1) Apex	322	21	6.5
(2) (3) 2 set	644	56	8.6
(4) (5) 3 set	644	63	9.7
(6) (7) 4 set	643	88	13.6
(8) (9) Butt	718	182	25.3

[1]Contribution No. 402 from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Texas. Received for publication July 9, 1928.

[2]Agronomist, Substation No. 5, Temple, Texas.

A study of these data reveals the fact that a progressive increase in motes is registered from apex to base. The percentage of motes increased gradually from 6 5 to 25 3% from tier to tier as the base of the lock was approached.

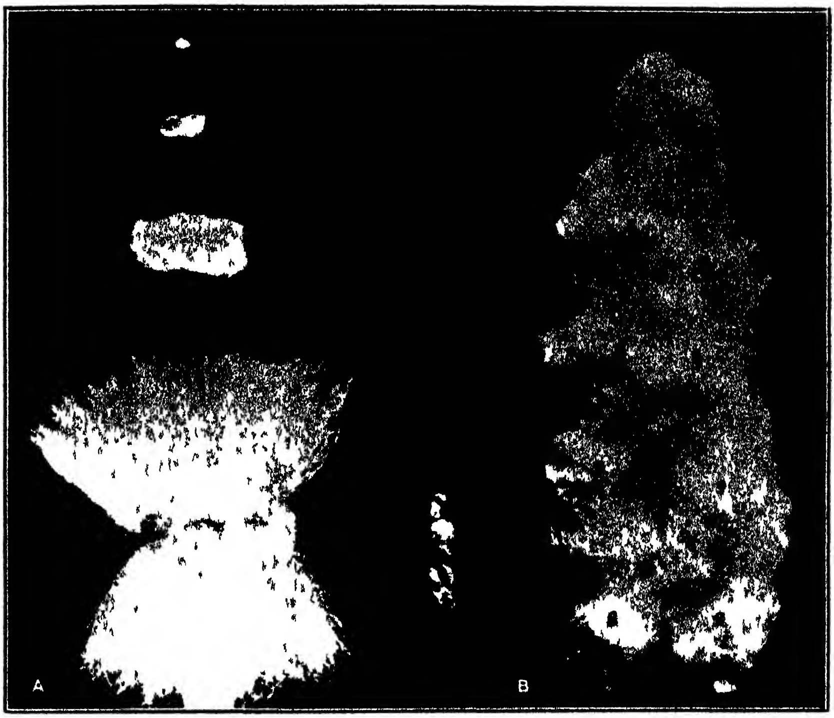

FIG 1.—(A) Top to bottom, a normal ovule at the time of fertilization, an aborted ovule, a sound ginned seed, and a sound unginned seed.
(B) Left to right, a lock in which all the seed are aborted and a perfect lock.

This location of motes is very interesting, but too much dependence cannot be put on a sample of 10 plants. An additional sample for study was secured in 1925. This sample consisted of the individual Belton cotton pedigree row No. 80 which was taken without any knowledge of its characteristics. This row was composed of 33 individual plants which produced a total of 762 normal locks. Of these locks 290 were perfect, while the motes produced in the remaining locks are charted in Table 2.

In this sample the percentage of motes increases from 11.1 at the apex to 38.5 at the base. An inspection of Table 2 will show that these records substnatiate those presented in Table 1.

TABLE 2.—*Location of motes in Belton plant to row No. 80, 1925.*

Grouping		Total seed	Total motes	Percentage motes
(1)		682	96	11.1
(2)	(3)	1,724	217	12.6
(4)	(5)	1,724	254	14.7
(6)	(7)	1,719	388	22.6
(8)	(9)	863	274	31.7
(10)	(11)	26	10	38.5

Added to these results are those taken on row No. 68 in 1926. This sample was also taken at random from the Belton pedigree row. This row produced 43 individual plants with a total of 2,443 normal locks, 315 of which were free from motes. Results on row No. 68 are given in Table 3, and a study of this table will reveal the same general distribution of motes as recorded in the first two tables.

TABLE 3.—*Location of motes in Belton plant to row No. 68, 1926.*

Grouping		Total seed	Total motes	Percentage motes
(1)		2,443	421	17.2
(2)	(3)	4,886	858	17.6
(4)	(5)	4,886	1,013	20.7
(6)	(7)	4,879	1,470	30.1
(8)	(9)	3,954	1,729	43.7
(10)	(11)	353	294	83.3

Occasionally an upland cotton lock is found with its apical seed paired, which gives it an even instead of an odd number of seed to the lock. For fear the original basis of classification might have influenced the results, the records on the three samples above were reclassified on the basis of a lock with an even number of seed. Identically the same results as before were obtained. The records on row No. 68 are given as typical of the classification on the basis of an even number of seed per lock. The apical pair of seed contained 17.1% of motes; the second pair, 19.1%; the third pair, 25.2%; the fourth pair, 37.3%; the fifth pair, 50.7%; and the sixth pair, 55.6%.

In Belton row No. 80 of 1925, 85 bolls were five-lock bolls and 124 were four-lock bolls. Belton row No. 68 of 1926 had 477 five-lock bolls and 42 four-lock bolls. The original records on the location of motes were taken with the individual lock as the unit so that reclassification as to the type of boll was possible. The percentage of motes in each location of a typical lock is given separately for five- and four-lock bolls for rows Nos. 80 and 68 in Table 4.

Again this analysis shows that the percentage of motes increases or decreases as the location of the individual ovule is near or far from he apex of the lock.

TABLE 4.—*Location of motes in Belton plant to rows Nos. 80 and 68 classified as to four- and five-lock bolls.*

Location		1925 Row 80 Percentage motes 5-lock bolls	1925 Row 80 Percentage motes 4-lock bolls	1926 Row 68 Percentage motes 5-lock bolls	1926 Row 68 Percentage motes 4-lock bolls
(1)		9.7	12.4	17.5	13.2
(2)	(3)	12.5	12.7	17.8	14.1
(4)	(5)	16.0	13.6	20.9	18.6
(6)	(7)	25.4	20.2	30.6	22.8
(8)	(9)	37.0	28.1	44.5	32.4
(10)	(11)	60.0	25.0	84.3	50.0

The distribution of motes in the individual lock as exhibited by the three samples would seem to preclude any suggestion that these motes were caused by inherited lethals. If there was any inherited weakness of the ovules themselves, one would expect a random distribution of the motes throughout the length of the lock. However, this distribution is such as would be expected if the ovules were aborted due to lack of food or moisture. Also, this distribution might be expected if certain ovules failed to develop due to lack of complete fertilization.

The process of fertilization of the cotton bloom is probably such as to place the seed at the base of the lock at a disadvantage in being reached by the pollen tube. The procedure of the pollen tube as it grows down through the tissues of the style has not been adequately described. However, it will appear that any pollen tube that enters the seed at the base of the lock would have had previous opportunity to enter any remaining virgin ovules near the apex. It is not unlikely that these motes are the result of several factors and cannot be accounted for completely by any one factor.

There exists a difference between the percentage of motes in a five-lock and a four-lock boll which it would be difficult as yet to assign to a single cause. The weighted average of these two types of bolls show 19.2% motes for the five-lock compared with 16.8% for the four-lock bolls in row No. 80 of 1925; and 27.5% for the five-lock compared with 20.5% for the four-lock bolls in row No. 68 of 1926. A re-inspection of Table 4 will bear out, except for two cases, the fact that a similar difference exists between these two types of bolls for the various tiers of seed from the apex to the base of the lock.

This difference between the relative number of motes as to the type of boll might be nutritional, resulting from the fact that there are only four-fifths as many seed in the four-lock as in the five-lock boll. Again it might be due to incomplete fertilization, since the five-lock boll has a greater number of ovules to be fertilized by about

the same amount of pollen that is available for the four-lock boll. Preliminary counts as to the average amount of pollen indicate an equal amount available for both types of bolls. Many of these details surrounding the occurrence of motes must be worked out more completely before a clear conception of the causal factors is to be had. The extent to which environmental and hereditary factors, particularly those factors connected with pollination and fertilization, may increase or decrease the percentage of motes is a subject of a study that is still under way. However, it seemed appropriate to report on the location of these motes at this time since the data appear to be rather conclusive.

EQUALITY OF KERNEL ROW NUMBERS IN RECIPROCAL CORN CROSSES[1]

FREDERICK D. RICHEY AND H. S. GARRISON[2]

INTRODUCTION

In an earlier paper the writers have called attention to differences in the numbers of kernel rows on the ears of reciprocal crosses between certain strains of corn previously mass selected for kernel row numbers.[3] It was pointed out that in each inequality the distribution of the ears with respect to number of kernel rows tended to be more like that of the pistillate parent strain. It was further noted that, "Whether this was due to some influence of the methods used or to inherent tendencies cannot be determined. In view of the facts that the pollinations were not strictly controlled by bagging, etc., and that the seed ears used to represent the different sorts were not selected, too much importance probably should not be attached to this difference."

The possibility of inequality between reciprocal crosses is of practical as well as theoretical importance. One of the writers already has called attention to inequality in the yields of reciprocal crosses between varieties of corn.[4] Differences in the yields of reciprocal crosses between selfed lines of corn are a common experience of those testing such crosses. Such differences, however, might so readily occur because of difference in seed size, condition, or the like, that they should offer little conclusive evidence as to germinal differences. Differences in the numbers of kernel rows, on the other hand, would be affected little, if at all, by differences in seed value. Accordingly, it seemed desirable to determine whether differences in numbers of kernel rows would be obtained under methods excluding the possible differential effects of the methods used in connection with the strain crosses. The present paper reports the results of such an experiment.

MATERIAL AND METHODS

Lines of C. I. No. 119 corn which had been selfed for four and five generations were used as parents. These selfed lines originated in the

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication July 13, 1928.

[2]Senior Agronomist in Charge of Corn Investigations and Assistant Agronomist, respectively.

[3]GARRISON, H. S., and RICHEY, F. D. Effects of continuous selection for ear type in corn. U. S. D. A. Bul. 1341, 10 pp. 1925.

[4]RICHEY, F. D. The inequality of reciprocal corn crosses. Jour. Amer. Soc. Agron., 12: 185–196. 1920.

TABLE 1.—*Yield and numbers of kernel rows on the ears of the reciprocal crosses between individual plants of selfed lines of corn at the Arlington Experiment Farm, Rosslyn, Va., in 1927.*

Comparison No.	Parent plant A* Family No.	Parent plant A* Kernel rows	Mean number of kernel rows Cross A x B	Mean number of kernel rows Cross B x A	Mean number of kernel rows Difference	Number of plats	Mean plant yield, pounds of dry ear corn Cross A x B	Mean plant yield, pounds of dry ear corn Cross B x A	Mean plant yield, pounds of dry ear corn Difference	Parent plant B* Kernel rows	Parent plant B* Family No.
1	127	8	13.56±.14	14.22±.16	0.66±.21	1	0.932	0.717	—0.215	18	22
2	127	8	15.13±.17	14.59±.21	—0.54±.27	1	0.943	0.943	0.000	20	9
3	127	8	16.09±.17	15.54±.16	—0.55±.23	2	0.824	0.870	0.046	20	9
4	127	8	16.15±.12	15.21±.18	—0.94±.22	2	0.816	0.597	—0.219	20	9
5	104	8	13.23±.24	13.84±.20	0.61±.31	2	0.868	0.877	0.009	20	9
6	104	8	14.29±.16	13.65±.16	—0.64±.23	1	0.734	1.008	0.274	20	10
7	110	8	13.53±.10	13.49±.11	—0.04±.15	2	1.103	1.085	—0.018	20	10
8	113	8	17.31±.10	17.24±.09	—0.07±.13	3	0 927	0.833	—0.094	28	19
9	127	8	16.37±.09	16.50±.10	0.13±.13	3	0.897	0.895	—0.002	28	19
10	127	8	16.30±.11	16.36±.14	0.06±.18	2	0.910	0.951	0.041	30	19
11	104	10	13.69±.11	14.14±.13	0.45±.17	2	0.727	0.757	0.030	18	9
12	117	10	14.41±.11	14.49±.12	0.08±.16	2	0.794	0.828	0.034	18	22
13	127	10	13.23±.09	13.28±.09	0.05±.13	3	0.862	0.831	—0.031	18	22
14	127	10	13.94±.07	13.71±.08	—0.23±.10	3	0.844	0.868	0.024	18	56
15	127	10	15.00±.19	14.92±.15	—0.08±.24	2	0.846	0.830	—0.016	20	9
16	127	10	14.24±.10	13.94±.09	—0.30±.13	3	0.882	0.992	0.110	20	22
17	104	10	14.08±.21	14.43±.12	0.35±.24	1	0.850	0.845	—0.005	20	9
18	113	10	14.83±.23	14.45±.24	—0.38±.33	1	0.881	0.872	—0.009	20	10
19	113	10	14.81±.20	14.42±.21	—0.39±.29	1	0.986	0.900	—0.086	20	10
20	104	12	15.41±.23	16.35±.21	1.21±.31	1	0.967	0.960	—0.007	20	9
21	98	12	17.86±.15	17.30±.15	—0.56±.21	2	1.069	1.019	—0.050	20	10
22	65	12	14.11±.15	18.29±.12	4.18±.19	3	0.907	1.063	0.156	24	10
23	98	12	18.84±.11	18.73±.12	—0.11±.16	3	0.956	0.946	—0.010	28	19
24	75	14	17.58±.26	18.09±.28	0.51±.38	1	0.969	0.952	—0.017	22	10
25	78	14	18.28±.18	17.96±.15	—0.32±.23	2	0.699	0.738	0.039	20	9

*Family number, and number of kernel rows on crossed parent ear.

strains mass selected for different numbers of kernel rows as described in the previous report.[5] One group of lines used was from strain 6 of the earlier experiment. These lines had been selected toward and were breeding fairly true for 8-, 10,- and 12-kernel rows. Another group, from strains 1 and 2 of the earlier experiment, had been selected for 18 or more kernel rows. Crosses were obtained between these groups in 1926, crossing two individual plants of the parent lines reciprocally. The 25 comparisons here reported are between such plant reciprocals.

The crosses were grown in 1927 in single-row plats containing 25 plants each as a perfect stand. Each pair of reciprocals was grown in a pair of adjacent plats and replicated as often as the available seed permitted. The number of pairs of plats of each pair of reciprocals is shown with the data. The product of one plat of each cross was hung in the laboratory until dry and the harvest weights were calculated to air-dry weights on the basis of this sample. The numbers of kernel rows were determined on all of the ears, averaging about 20 ears per plat.

EXPERIMENTAL DATA

The mean yield and the mean number of kernel rows for each cross and its reciprocal, together with the differences between reciprocals, are shown in Table 1.

Of the 25 differences in numbers of kernel rows, 14 are in one direction and 11 in the other, a deviation from equality of 1.5 ± 1.69. Moreover, the differences between the reciprocals in terms of their probable errors are in reasonable accord with expectations based on random sampling in a single population. Accordingly, there is no evidence of systematic inequality between reciprocals in this experiment, such as was noted in the crosses of the parent strains.[5]

Some of the differences in numbers of kernel rows are so large that they would be expected to occur very rarely due to errors of random sampling. Particularly, the difference in comparison 22 is 22 times its probable error and the odds against a chance deviation of that order are practically infinite. Again, a difference as large as those in comparisons 1, 4, and 20 would be expected to occur less than once in 100 random samples from a normal population. Nevertheless, here are 3 such differences in 25 samples. It seems clear, therefore, that some of the differences are not within the limits of random sampling. There is nothing in these data, however, to indicate to what they are due.

[5] Garrison, H. S., and Richey, F. D. *Op. cit.*

The differences in the yields of the reciprocal crosses are presented more for completeness than because of significance. Here, too, 14 differences were in one direction, and 11 in the other. None of the differences, however, can be considered significant in view of the small number of replications.

The absolute yields of the crosses are of passing interest as indicating their productiveness. These crosses constitute part of a preliminary series to determine which selfed lines combine to best advantage. Plant yields of 1.00 pound in these experiments represent acre yields of approximately 100 bushels. Considering the averages of the reciprocals, 3 of the 25 combinations exceeded an acre yield of 100 bushels, promising well for the breeding program.

TYPES OF FIELD AND PLAT IN CROP TESTS[1]

G. H. STRINGFIELD[2]

This paper reports studies on the variability among test plats of small grains under two general headings. First, are considered the effects on deviation from varying the size of planting or total area given over to a test. In this connection some consideration is given to shape of plantings as affecting variation. Second, studies are reported on the reliability of several plat types differing from each other in both size and shape.

MATERIAL AND METHODS OF ATTACK

Nursery tests made up of small plats planted by hand or with specially adapted machinery and general field tests comprising larger plats planted with ordinary grain drills were included in these studies.

Five years' data from general oat and wheat nurseries were used, and also data from four nurseries planted especially for studies of methods. The latter will be referred to as method-study nurseries as opposed to the general nurseries, which were primarily for variety tests.

Among field plats, the Ohio Station has for many years been using hundredth-acre plats and tenth-acre plats in variety testing. In 1926 a method-study planting of hundredth-acre plats was grown.

Checks were placed at regular intervals in all the general nursery and field tests. Checks are merely controls, all planted to the same variety of grain and given uniform treatment. Most of the data in this paper were taken either from check plats or from method-study plantings.

The influence of field-size on variability was studied by dividing the plantings into blocks of various areas and finding the deviation within the blocks.

Types of plats were made up in the nurseries by beginning with the smallest unit which was a single row, 1 rod long, then synthesizing larger plats by adding rows to the side, or to the end, or both. The variation exhibited by each type was found.

Synthesizing was possible among the field plats only in the field method-study planting of 1926. Among other field plantings it was

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. An abridged form of a thesis submitted to Ohio State University in partial fulfillment of the requirements for the degree of master of science. Published with the approval of the Director. Received for publication July 13, 1928.

[2]Assistant Agronomist. The writer is greatly indebted to Professor L. E. Thatcher for continued helpful suggestions in the preparation of this paper, and also to Professors R. M. Salter, J. B. Park, and R. J. Garber (University of West Virginia) for kindly criticisms.

necessary to make comparisons between different fields. Fields of equal plat capacity rather than of equal area were compared.

The merit of any given type was estimated by its standard deviation. The formula used was S. D. $=\sqrt{\frac{\Sigma d^2}{n}}$, where d equals the deviation, and n the number. No correction for small numbers was attempted. It seemed that, for purposes of comparison, the systematically distributed plats were including the major soil differences fairly well. Numerous trials showed that use of the formula S. D. = $\sqrt{\frac{\Sigma d^2}{n-1}}$ would have caused no important changes in the results. In summarizing the tables weighted means of the standard deviations were used. The separate standard deviations were weighted according to the numbers used in finding them.

In the earlier calculations the procedure was to summate d^2 for all groups concerned, divide by the total number, and extract the square root. Results from this method generally agree very closely with those obtained from the ordinary method of weighting a mean according to the numbers involved in the separate determinations, and for the sake of simplicity no distinction is made in this paper. This method differs from Hayes (7)[3] "Deviation from the Mean Method" in that deviations here are actual values rather than percentage values.

The frequent literature reviews of recent date on the general subject of field plat technic would make an additional one in this paper seem unnecessary. In addition to specific citations the reader is referred to the report of the Committee on Standardization of Field Experiments (20) of the American Society of Agronomy.

SIZE AND SHAPE OF FIELD

Stadler (17) has published data showing the increase in variability as experiment fields were enlarged at Missouri.

Details of the nursery data will be considered first. For the plan of a small grain nursery see Fig. 1, Block e. The lines represent check rows. The check rows occurred in threes. Each three make a check plat. Checks were placed at every sixth position, that is, five plats intervened from one check to another. Rows were 1 foot apart, both within and between plats, and plats were approximately 1 rod long. The plantings were in three ranges and the ranges were separated by aisles usually 2 feet wide. The check plats were so placed that they fell end to end with checks in opposing ranges, thus making strips across the planting each containing nine single rod-

[3]Reference by number is to "Literature Cited," p. 1095.

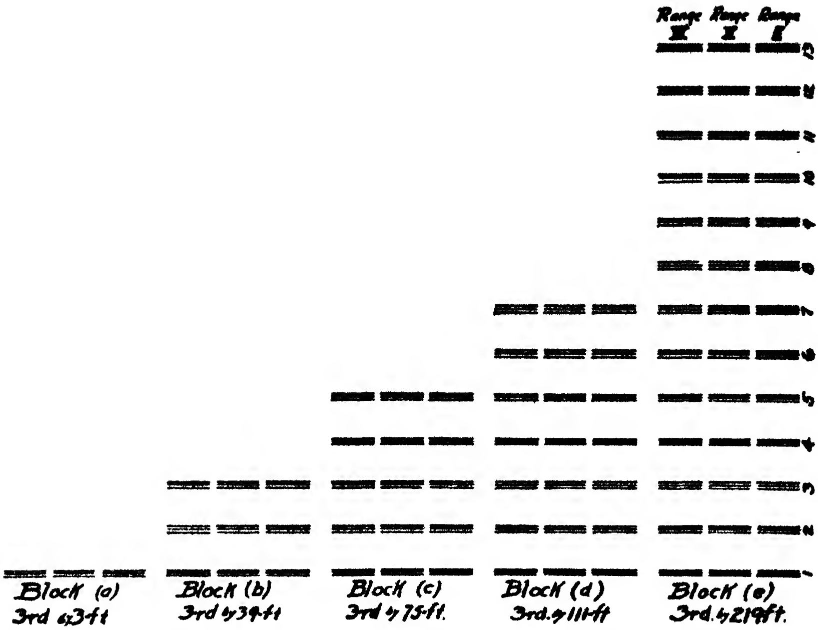

FIG. 1.—The relative sizes of blocks used for studying the effect of area on variability in Wooster cereal nurseries.

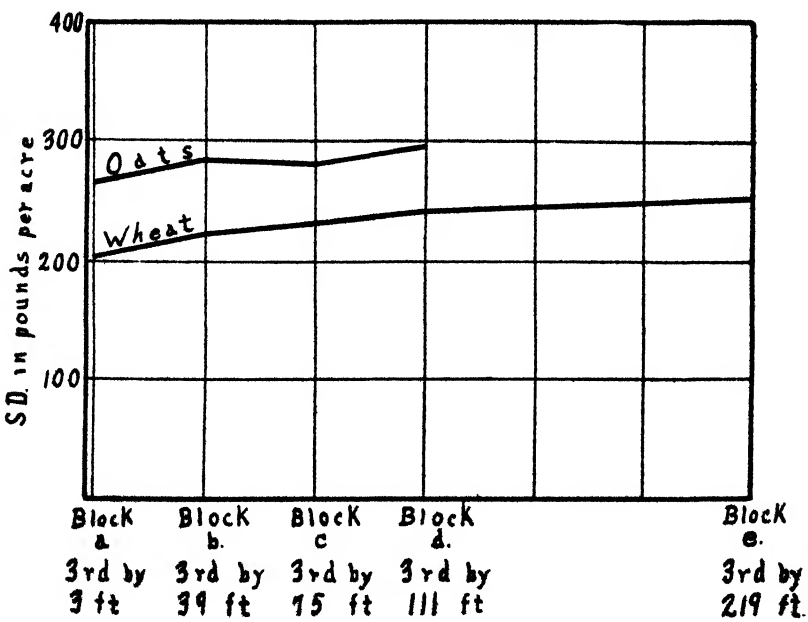

FIG. 2.—The standard deviations obtained from single-rod rows in blocks of increasing size.

rows. These strips of nine single rod-rows were made the units in dividing off the plantings. They are numbered in Fig, 1. Block e.

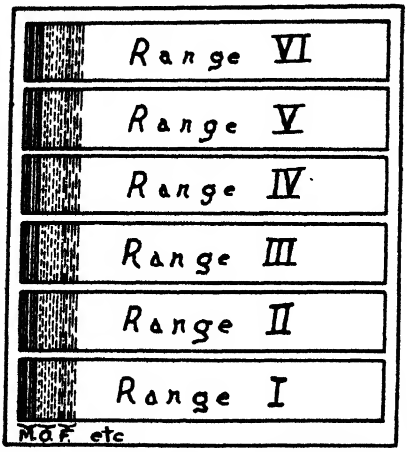

FIG. 3.—Plan of the oat method-study nursery planting in 1926. Three varieties, Miami, Ohio 201, and Fulghum, were planted in continuous series of six-row plats. Two-foot alleys cut the rows into approximately 1-rod lengths. The total planting was 108 rows wide by 6 rods long, exclusive of alleys and six unweighed border rows.

Fig. 1 is drawn roughly to scale and indicates the relative sizes of the blocks used for the study on size of nursery. With Block e as the undivided planting, lesser blocks were made up as follows:

Block size a.—Each is a single strip of nine rows. Thirteen blocks were made from the planting.

Block size b.—Four blocks were made by the following combinations, strips 1 to 3, 4 to 6, 7 to 9, and 10 to 12.

Block size c.—Three blocks were made by combining strips 1 to 5, 5 to 9, and 9 to 13. Strip 5 was included in two blocks here, as was also strip 9. Either of these strips, however, might exert quite different influences on the two blocks including it.

Block size d.—Two blocks were made by combining strips 1 to 7 and 7 to 13. In the oat data, Block d was the maximum size.

The mean standard deviations among the single rod-rows for each block size, as obtained from the oat plantings, are shown in Table 1 and the wheat data in Table 2. The results are charted in Fig. 2.

TABLE 1.—*Effect of size of block on average standard deviation (in bushels per acre) of single rows in nursery oats.*

See also Fig. 2.

Year	Block a 3 rods by 3 feet	Block b 3 rods by 39 feet	Block c 3 rods by 75 feet	Block d 3 rods by 111 feet
1921	4.59	4.94	4.48	5.32
1922	7.10	7.32	7.56	7.58
1923	9.48	10.35	9.15	10.85
1924	11.26	12.56	12.74	11.97
1925	8.98	9.24	9.88	10.28
Weighted mean*	8.28 (369)	8.88 (324)	8.76 (270)	9.20 (369)
Total number of blocks	41	12	6	6

*Number of plats used are shown in parentheses.

TABLE 2.—*Effect of size of block on average standard deviation (in bushels per acre) in nursery wheat.*

See also Fig. 2.

Year	Block a 3 rods by 3 feet	Block b 3 rods by 39 feet	Block c 3 rods by 75 feet	Block d 3 rods by 111 feet	Block e 3 rods by 219 feet
1921					
Field I	2.72	3.19	3.30	3.74	3.78
Field II	2.53	2.99	3.50	3.49	3.51
1922	2.51	2.68	2.73	2.81	3.07
1924					
Field I	3.41	3.58	3.48	3.49	3.72
Field II	3.72	3.98	3.92	4.13	4.22
1925	4.63	4.81	4.86	4.82	4.93
1926	3.96	4.69	5.26	5.44	6.28
Weighted mean*	3.35 (819)	3.70 (756)	3.86 (945)	3.99 (882)	4.22 (819)
Total No. of blocks	91	28	21	14	7

*Number of plats are shown in parentheses.

A study on size of field was also made using the method-study oat nursery of 1926. Fig. 3 shows the scheme of this planting. As before rows were approximately 1 rod long and 1 foot apart. The use of

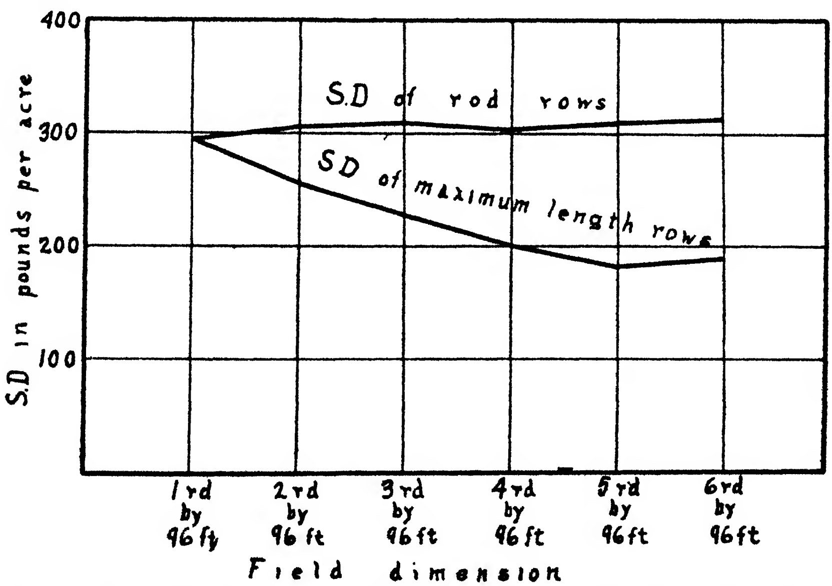

FIG. 4.—Showing how standard deviation was affected by increasing size of blocks and by increasing length of row in the oat method-study nursery, 1926. The upper line shows the standard deviations obtained from single rod-rows in blocks of increasing size. The lower line shows the standard deviations obtained from rows of increasing length.

three varieties in continuous series of six-row plats was for purposes other than the present consideration. In finding the standard deviations each variety was treated separately and the results averaged.

The smallest blocks, six in number, each included one range. Each successive block was made one range larger than the preceding one. There were thus three blocks of the second size made up by the three following combinations; Ranges I and II, III and IV, V and VI.

There were two blocks of the third size, each containing three ranges, *viz.*, I to III, and III to VI. The fourth size included ranges I to IV; the fifth size, ranges I to V; and the sixth, ranges I to VI. Standard deviations for the different areas are shown in Table 3 and are charted in Fig. 4, top line.

TABLE 3.—*Effect on variability, expressed as standard deviation in bushels per acre, from increasing size of block in the 1926 oat method-study planting.*

See also Fig. 4, top line.

Size of field	Ranges included	Miami	Ohio 201	Fulghum	Average*
96 feet by 1 rod	Each range	9.48	10.05	8.04	9.15 (609)
96 feet by 2 rods	(DE), (FG), (HI)	9.74	10.27	8.69	9.53 (609)
96 feet by 3 rods	(DEF), (GHI)	9.76	10.26	8.98	9.64 (609)
96 feet by 4 rods	(DEFG)	9.56	10.50	8.31	9.37 (410)
96 feet by 5 rods	(DEFGH)	9.67	10.13	9.15	9.63 (506)
96 feet by 6 rods	(DEFGHI)	10.02	10.29	8.84	9.69 (609)

*Number of plats shown in parentheses.

Like the nursery method-study, the field method-study was laid out primarily for purposes other than to show the effect of field size on variability, but it lends itself to such treatment. (See Figs. 5 and 6.) Unweighed border plats were grown at the ends of the ranges and the space between the ranges was seeded. Essential details of planting arrangement are shown in Fig. 6. Only the Miami plats were used in the A (east) and A (west) ranges. The field was blocked off as follows:

Blocks of the first size, six in number, each included one range. The fact that these ranges varied somewhat in actual area is not of much importance as the complete results will show.

Blocks of the second size, three in number, each included two ranges. Those of the third size, two in number, each included three ranges, and the fourth size included the entire field. The average

standard deviations for blocks of each size are shown in Table 4 and charted in Fig. 7.

TABLE 4.—*Size of block (hundredth acre plats), as affecting standard deviation in bushels per acre in the field method-study oats, 1926.*

See also Fig. 6.

Plat capacity	Ranges included	Average standard deviation*
44 to 60	Each range	6.12 (247)
104 to 120	(A), (BC), (DE)	6.38 (247)
134	(AB), (CDE)	6.61 (247)
268	(ABCDE)	6.72 (247)

*Number of plats shown in parentheses.

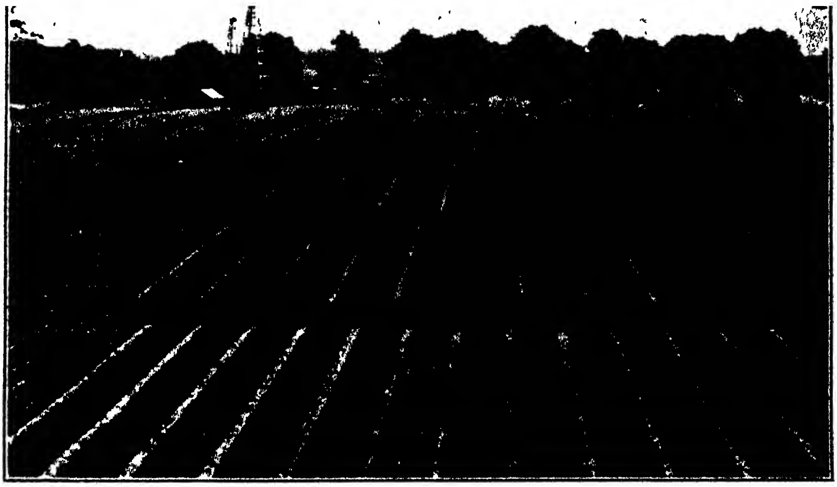

FIG. 5.—Hundredth acre oat plats of two widths as grown in the 1926 field method-study planting. Plats of this type seem more practical for variety tests than the tenth-acre plats shown in Fig. 8.

The next study on the influence of field size was made using checks in the general variety-test plantings. These plantings were of two types, in one, the plats were one-hundredth acre and in the other they were one-tenth acre.

The hundredth-acre variety test plats were planted on several different fields about the Station from year to year. Checks were included only in part of the years. Data from these years only can be studied. The types of planting also have not been alike in all years, but the scheme generally used was to lay out one continuous range of plats. For uniformity the capacity of the fields in these comparisons was arbitrarily limited to 76 plats.

The tenth-acre variety test plats were grown on four fields, being in a four-year rotation on the Variety Range. (See Fig. 8.) They

were in each case grown in one continuous range, and computations were again limited to fields with capacities of 76 plats. Checks were spaced as follows:

TABLE 5.—*Effect on standard deviation in bushels per acre of doubling the plat capacity of Wooster fields.*

See also Fig. 9.

Crop	Size of plat	Number of years represented	Standard deviation Plat capacity of 37	Standard deviation Plat capacity of 76
Oats	1/100 acre	4	4.54	5.12
Oats	1/10 acre	17	4.74	5.22
Wheat	1/100 acre	9	2.58	3.00
Wheat	1/10 acre	17	2.61	2.85

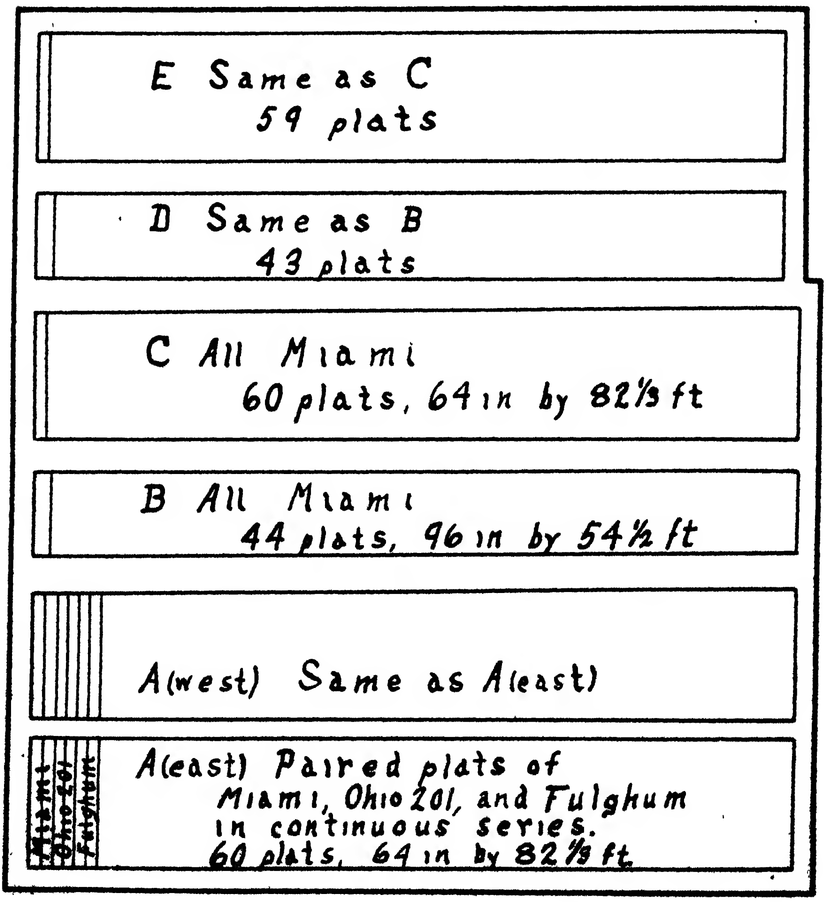

FIG. 6.—Plan of the field method-study oats, 1926. Hundredth-acre plats separated by 2 foot aisles.

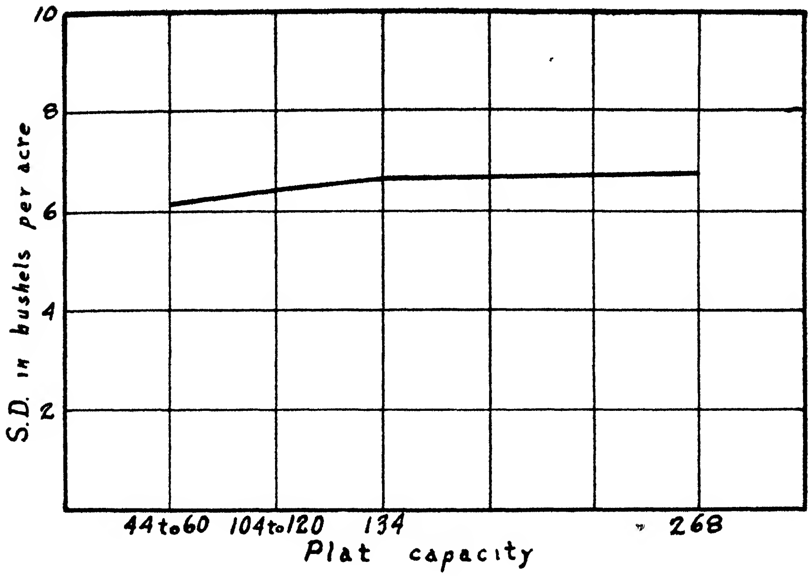

FIG. 7.—Standard deviations for blocks of increasing plat capacity in the field method-study oats, 1926.

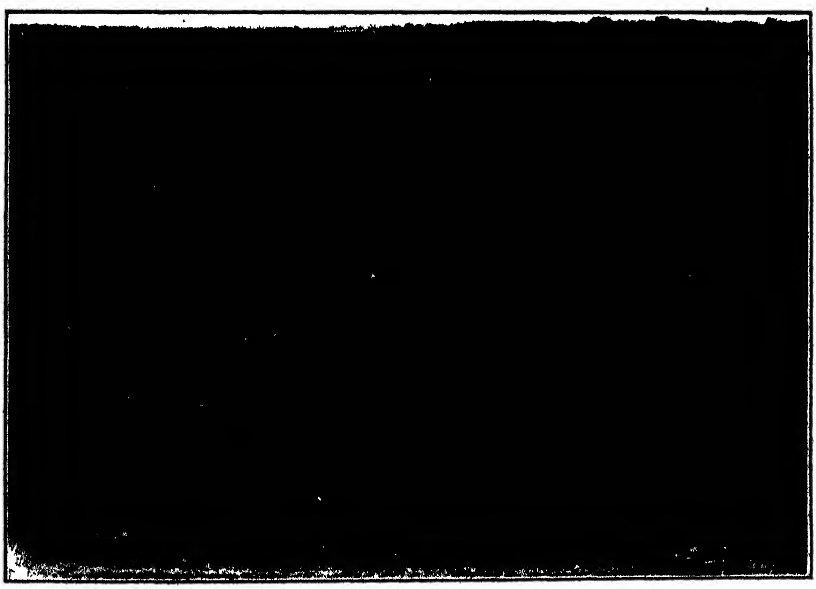

FIG. 8.—Tenth-acre wheat and oat plats used in variety testing.

Oats hundredth-acre plats, checks at each sixth position
Oats tenth-acre plats, checks at each fourth position
Wheat hundredth-acre plats, checks at each sixth position
Wheat tenth-acre plats, checks at each third position

Standard deviations for blocks of two sizes, having total plat capacities of 37 and 76, respectively, were found. These are shown in Table 5 and are charted in Fig. 9.

DISCUSSION OF FIELD SIZE AS AFFECTING VARIATION

The above tests were made on scattered fields of Wooster silt loam soil. It was naturally well drained, and in addition, was tiled and kept in good fertility by applications of barnyard manure and commercial fertilizers. One exception in soil type is that the 1926 field method-study oats were on Canfield silt loam. Changes of soil type and marked differences in topography did not occur within the fields.

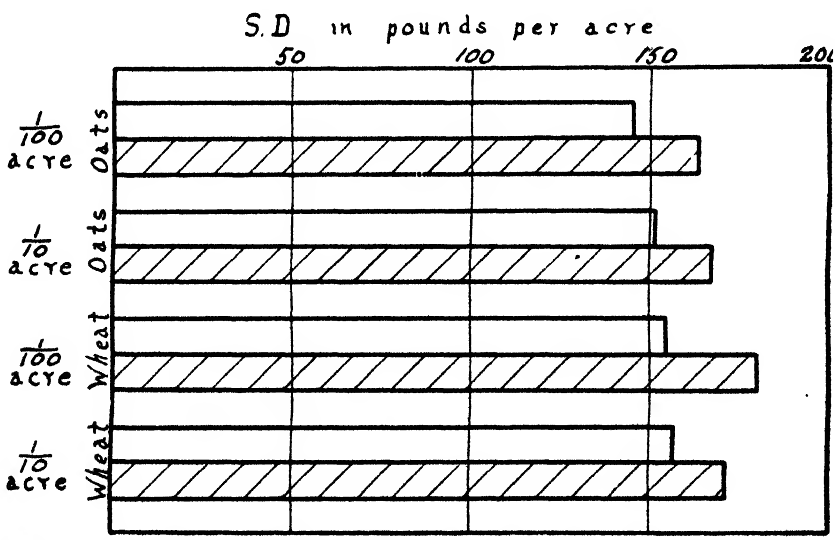

Fig. 9.—The effect on standard deviation of doubling plat capacity in plantings of hundredth-acre and tenth-acre plats. The blank columns indicate the average standard deviations for fields with plat capacities of 37 and the lined columns for fields with plat capacities of 76.

The results indicate that, in general, fields which show only moderate increases in variability with added area have been used for test plats. It is probably unnecessary to state that such results cannot be given general application. On other soils it would be hazardous to apply them without previous study, even to fields apparently uniform.

From the standpoint of certain problems in plat technic, however, it is of value to know that the yield differences found in small areas covered the major part of the total variation in the entire test fields. Such was the case in the Wooster cereal nurseries. Within the limits of the areas studied, this information would tend to emphasize local differences, say those encountered in the course of 3 or 4 rods. It is true that not all the variations in the smaller blocks were due to soil differences. Mechanical errors were probably mostly measured in the smaller blocks and would add little to the standard deviation as area was added.

The nursery results would seem to argue for the use of plats which are long enough to include the major local changes. This point will be considered later.

The results further add confidence to plat replication over areas as large as those studied.

In making comparisons on the reliability among nursery plats of different sizes, as will be done in the next section, it seems unnecessary to limit the smaller plats to areas proportional to their size. The smaller plats do, however, suffer a slight handicap when compared with larger plats on equal areas of ground.

The field plats (hundredth-acre and tenth-acre) showed unmistakable gains in variability when 37-plat ranges were doubled in length. A difference in standard deviation of 0.5 bushel in oats and 0.25 bushel in wheat suggests the advisability of using areas of ground proportional to the plat size when comparing these types in reliability.

As would be expected, the addition of area to the sides of a range, causing the enlarged field to approach a square, produced much more moderate increase in variation than extending the field in its longer dimension by addition at the end, as shown by a comparison of the field method-study oats, 1926 (Table 4), with the general field plats (Table 5). The method-study oats reached an approximate square after the original single range had been increased five times. The increase in standard deviation at this point is about the same as was obtained from merely doubling the size of the general plantings by extending the length. This comparison is crude, but it may call attention to the geometrical advantage of a square test field as opposed to the more popular rectangular range. The merits of the individual field must of course be considered.

SIZE AND SHAPE OF PLATS

In general, plat variability is reduced by increasing the size of the plat but less rapidly than by adding the area as distributed replicates. These conclusions have a wide experimental basis in the work of

Morgan (14), Wood and Stratton (21), Mercer and Hall (11), Hall and Russell (5), Montgomery (12, 13), Kiesselbach (9), Day (1), Stadler (17), Hayes (6), Summerby (19), McClelland (10), Odland and Garber (15), and others.

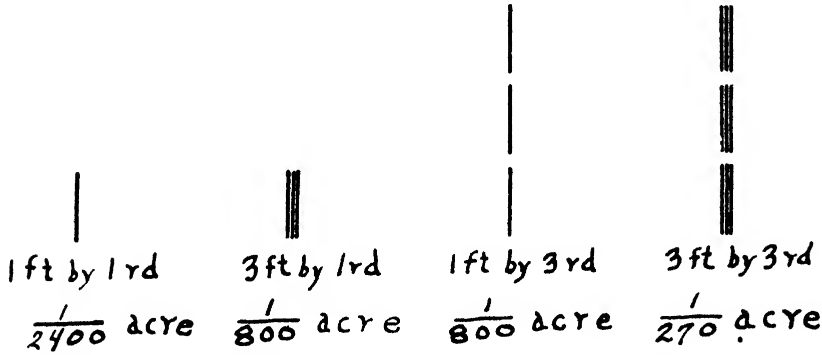

FIG. 10.—The four types used in studying the influence of size and shape among nursery plats.

That long narrow plats have certain advantages over the short wide type has also been in rather general agreement. Certain investigators have emphasized the value of square or short rectangular plats arranged in a chess-board plan, including Fisher (3, 4), Russell (16), Engledow and Yule (2), and Jones (8). The chess-board method for laying out plats seems to lend itself well to the calculation of error.

No size and shape optimum for all conditions has been or can be stated. The work reported in this paper is a series of comparisons among several types.

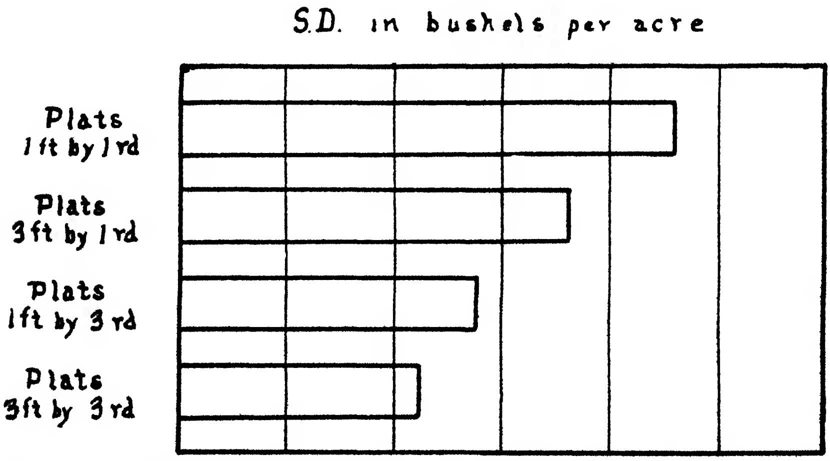

FIG. 11.—Average standard deviations among four types of check plats in oat variety nurseries.

Nursery plats will be considered first. Reference has already been made to Fig. 1, Block e, which shows the general plan of a small grain nursery.

Fig. 10 shows the types of plats compared. By combining single rod-rows, shown at the extreme left of the figure, the other three types were produced. For the following comparisons blocks 3 rods wide by 112 feet long, exclusive of alleys and borders, were used. This corresponds to Block d in Fig. 1. Such a planting will accommodate 333, 111, 111, and 37 plats, respectively, of the four types described. Except in the method-study plantings, only check plats, which were systematically distributed and covered about one-sixth of the total area, were included.

Standard deviations obtained in oat general nurseries and wheat general nurseries are given in Tables 6 and 7, and are charted in Figs. 11 and 12.

TABLE 6.—*Standard deviation in bushels per acre for four plat types in oat variety nurseries.*

See also Fig. 11.

Year	Type of plat*: 1 foot by 1 rod	3 feet by 1 rod	1 foot by 3 rods	3 feet by 3 rods
1921	4.74 (63)	3.07 (21)	3.61 (21)	2.90 (7)
1922	7.49 (54)	7.19 (18)	4.23 (18)	3.24 (6)
1923	10.49 (63)	8.64 (21)	6.93 (21)	6.78 (7)
1924	11.81 (63)	7.88 (21)	6.19 (21)	3.29 (7)
1925	10.04 (54)	8.82 (18)	7.54 (18)	6.57 (6)
Weighted mean	8.92 (297)	7.07 (99)	5.69 (99)	4.53 (33)

*Number of plats given in parentheses.

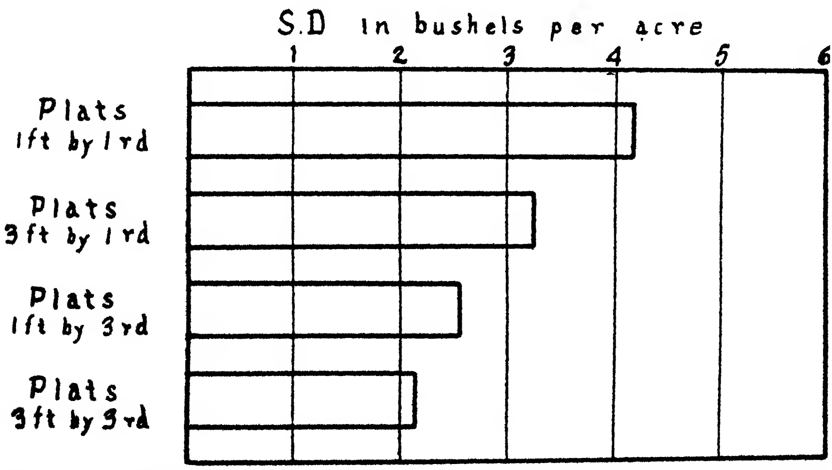

FIG. 12.—Average standard deviations among four types of check plats in wheat variety nurseries.

TABLE 7.—*Standard deviation in bushels per acre for four plat types in wheat nurseries.*

See also Fig. 12.

Year	Type of plat* 1 foot by 1 rod	3 feet by 1 rod	1 foot by 3 rods	3 feet by 3 rods
1921	3.98 (252)	2.96 (84)	2.52 (81)	2.37 (27)
1922	2.70 (89)	1.94 (64)	1.62 (63)	1.14 (21)
1924	3.66 (252)	2.60 (84)	2.07 (84)	1.48 (28)
1925	3.92 (126)	3.42 (42)	2.07 (42)	1.35 (14)
1925 (MS)	4.57 (324)	3.63 (108)	2.72 (108)	2.20 (36)
1926	5.44 (126)	4.73 (42)	3.98 (42)	3.67 (14)
Weighted mean	4.13 (1,169)	3.13 (424)	2.45 (420)	1.99(140)

*Number of plats given in parentheses.

Method-study oat nurseries were grown in 1924, 1925, and 1926. As an aid in studying effects of competition and the use of check plats, three varieties were grown each year in continuous series, that is, a, b, c, a, b, c, etc. The 1926 oat method-study nursery is charted in Fig. 3. These nurseries were blocked into areas to conform, as nearly as possible, to that used in the general nurseries. The standard deviation for each of the four plat types was found independently for the different varieties. The results were averaged and are presented in Table 8 and Fig. 13.

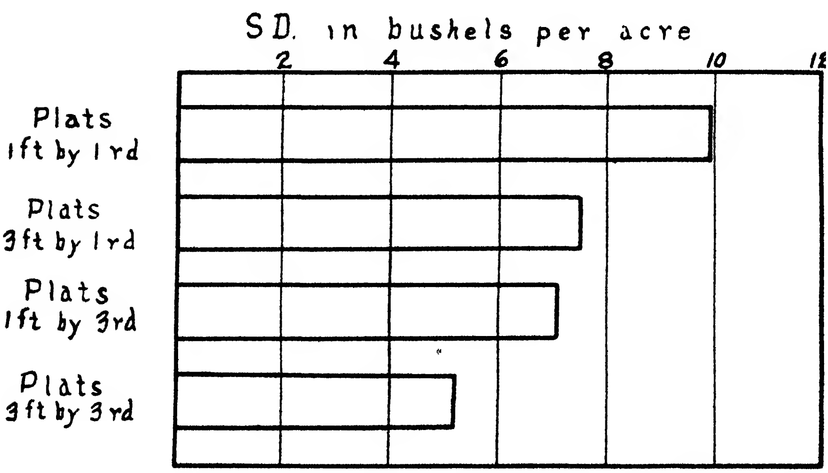

FIG. 13.—Average standard deviations among four types of plats in oat method-study nurseries.

From Tables 6, 7, and 8 two matters of interest may be noted. First is the decrease in variation of yield as the size of plat increased. Tripling plat size decreased the standard deviation from 20 to 40%. Second, lengthening the plats has been relatively more effective in

TABLE 8.—*Standard deviation in bushels per acre for four plat types in oat method-study nurseries.*

See also Fig. 12.

Year	Type of plat* 1 foot by 1 rod	3 feet by 1 rod	1 foot by 3 rods	3 feet by 3 rods
1924	10.37 (324)	7.73 (108)	7.27 (108)	5.15 (36)
1925	10.65 (536)	8.06 (155)	7.04 (194)	4.78 (47)
1926	9.65 (609)	7.31 (180)	7.09 (192)	5.49 (64)
Weighted mean	10.17 (1,469)	7.67 (443)	7.11 (494)	5.18 (147)

*Number of plats given in parentheses.

reducing variability than has widening them. In 13 of the 14 plantings involving about 1,000 plats of each type, those 1 row by 3 rods (fourth column) have a lower standard deviation than their competitors of equal area but which were three times as wide and one-third as long (third column). Tables 9 and 10 show the reduction of standard deviation in percentage by widening versus lengthening nursery plats. (See also Fig. 14.)

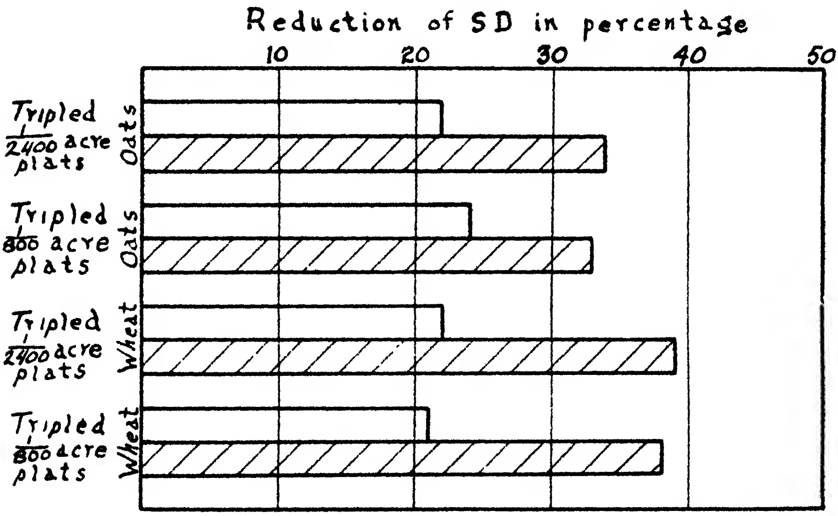

FIG. 14.—The reduction of standard deviation in percentage as obtained by widening versus lengthening nursery cereal plats. Blank columns indicate reduction by tripling width and lined columns indicate reduction by tripling length. The percentage reduction is in terms of the deviations found for the plat sizes designated at the left.

Information on the effect of extending the length of the row beyond 3 rods was obtained from the previously described 1926 oat method-study nursery (Fig. 3). By combining single rod-rows the following lengths were made up: 1 rod, 2 rods, 3 rods, 4 rods, 5 rods, and 6 rods. In Table 11 is shown the average standard devi-

TABLE 9.—*The reduction of standard deviation in percentage by widening versus lengthening nursery oat plats.*

	Oat nursery checks					Oat method-study			
	1921	1922	1923	1924	1925	1924	1925	1926	Average
	Reduction in percentage by tripling width								
Of single rod-row	35	4	18	33	12	25	24	24	22
Of single 3-rod row	20	23	3	47	13	29	32	23	24
	Reduction in percentage by tripling length								
Of single rod-row	24	44	44	48	25	30	30	27	34
Of triple rod-row	6	55	22	58	26	33	41	25	33

TABLE 10.—*The reduction of standard deviation in percentage by widening versus lengthening nursery wheat plats.*

	1921	1922	1924	1925	1925*	1926	Average
	Reduction in percentage by tripling width						
Of single rod-row	26	28	29	13	21	13	22
Of single 3-rod row	6	30	29	35	19	8	21
	Reduction in percentage by tripling length						
Of single rod-row	37	40	43	48	40	27	39
Of triple rod-row	20	41	43	61	39	22	38

*Method-study nurseries.

ation for each row length from 1 to 6 rods. These results are charted in Fig. 4, lower line. In this figure the fact that the top line (which shows the standard deviation of single rod-rows) goes up only slightly indicates that the total variation of the field was not greatly increased as area was added. With this in mind one would not expect that the lowered standard deviation for the rows of maximum length would have been much different had all lengths been compared in blocks of the same area.

TABLE 11.—*Effect on variability (expressed as standard deviation in bushels per acre) of increasing length of rows in the 1926 oat method-study planting.*

Length of row in rods	Ranges included	Oat Variety* Miami		Ohio 201		Fulghum		Average	
1	Each range	9.48	(209)	10.05	(186)	8.04	(214)	9.15	(609)
2	(DE), (FG), (HI)	8.11	(99)	8.22	(85)	7.74	(106)	8.01	(290)
3	(DEF), (GHI)	6.82	(67)	7.55	(54)	6.99	(71)	7.13	(192)
4	(DEFG)	6.23	(34)	6.25	(32)	6.27	(36)	6.25	(102)
5	(DEFGH)	5.62	(35)	5.55	(28)	5.86	(35)	5.69	(98)
6	(DEFGHI)	5.64	(35)	6.46	(27)	5.92	(35)	5.97	(97)

*Number of plats given in parentheses.

It is not to be expected that if the experiment were repeated in different places the lower line in Fig. 4 would follow the same little backward turn after the fifth rod. Variation is probably normally reduced at an increasingly slower rate as length of rows is increased

APPLICATION TO NURSERY PRACTICE

The statistical advantage of long single-row plats over wide plats of equal area has been demonstrated. Furthermore, with precaution in grouping, the single-row plats seem not to be measurably handicapped by effects of competition at Wooster (18). The long single-row plats must meet two other conditions. They must be usable from the standpoint of routine nursery practice, and they must compete satisfactorily with equal areas given over to distributed shorter plats.

At the Ohio Station a row longer than 3 rods seems at present too large for a convenient nursery unit. Later developments in handling nursery material might change this. A 3-rod row, however, makes a convenient bundle and has not been found cumbersome from any nursery standpoint. An exception might be made in the case of bearded barleys.

Accepting the data in Tables 6, 7, and 8, one may find by calculation that the variability for single 3-rod rows is generally, but not consistently, somewhat higher than the theoretical variability of the means for three distributed 1-rod rows. In the 1926 oat method-study no length of row showed as low variability as could theoretically be obtained from the means of distributed shorter rows totalling the same area. If, then, available land were the only consideration, it would seem that the smaller the plat unit the better. But the labor factor must also be considered. Three distributed 1-rod plats require more labor than a single 3-rod plat.

Using the summaries from Tables 6, 7, and 8, which are recognized as decidedly rough data, the ratios[4] of the theoretical numbers of 3-rod

[4]On the basis that the precision of a determination increases with the square root of the number of observations, $S.D._m = \frac{S.D.}{\sqrt{n}}$, where $S.D._m$ is the standard deviation for the means of n-sized groups made up of randomly chosen observations, and where S. D. is the standard deviation of the population from which the groups were taken. It follows that $\sqrt{n} = \frac{S.D.}{S.D._m}$ and $n = \left\{\frac{S.D.}{S.D._m}\right\}^2$. Since this equation holds for a group of any size, the following proportion may be stated where S. D. and S. D.′ are the standard deviations of 3-rod plats and 1-rod plats, respectively; where n and n′ are the numbers of plats, respectively; and where $S.D._m$ is an arbitrarily chosen value:

$$n : \left\{\frac{S.D.}{S.D._m}\right\}^2 :: n' : \left\{\frac{S.D.'}{S.D._m}\right\}^2, \text{ and}$$

$$n : n' :: \left\{\frac{S.D.}{S.D._m}\right\}^2 : \left\{\frac{S.D.'}{S.D._m}\right\}^2, \text{ or}$$

$$n : n' :: (S.D.)^2 : (S.D.')^2$$

plats to 1-rod plats needed to reduce the standard deviations to a common value were calculated. The ratio should be as the ratio of the squares of the standard deviations. The following were obtained with 1.0 respresenting 3-rod plats and the corresponding values 1-rod plats:

Oat general nurseries............1.0:2.5
Oat method-study nurseries......1.0:2.0
Wheat, all nurseries.............1.0:2.8

This looks as though it has been requiring somewhere between two and nearly three 1-rod plats to be of the same value as one 3-rod plat. It is questionable whether the smaller units can compete under these conditions. At present the Ohio Station is trying out 3-rod single row plats, with replications, and a seed series of three-row plats in which only center rows are used for seed.

NURSERY VERSUS FIELD PLATS

A rough comparison between 1/270-acre nursery plats and tenth-acre field plats was made by noting the regularity with which the two plat sizes maintained the average ranks of 22 wheat varieties over a period of five years. With a few substitutions the 22 varieties were identical for the two types. None of the yields were adjusted to checks.

The method was as follows, considering first the nursery plats: The mean of the 22 varieties was found for each year. Taking a given variety, Fultzo Mediterranean, for instance, the yield in percentage of the mean for all varieties was found in each year. Fultzo Mediterranean's record for the five years is as follows:

Year	Yield in percentage of the means for 22 varieties	Deviation
1921	96	+3.8
1922	90	—2.2
1923	97	+4.8
1924	92	—0.2
1925	86	—6.2
Average	92.2	

A similar record for each of the other 22 varieties was made and the average standard deviation was found to be 8.57. This 8.57 is in terms of percentage of the mean yields for the 22 varieties.

The average standard deviation for the 22 tenth-acre plats was 7.82. This is probably not significantly lower than that obtained from the nursery plantings.

It is possible that in responding differently to unlike seasons, varieties would often show considerable fluctuation in rank from

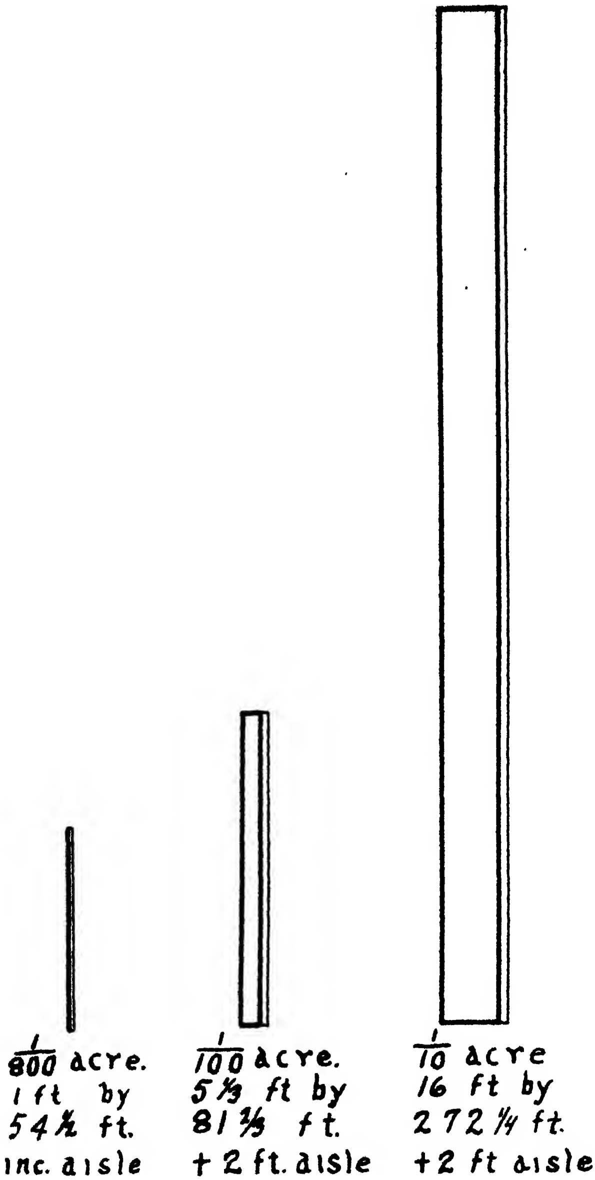

FIG. 15.—Relative sizes of three plat types with aisles. The eight-hundredth size is a nursery plat, and the other two are field plats.

year to year. Unpublished data in connection with the use of check plats would indicate, however, that significant differences in plat

reliability may be registered in terms of these inter-annual deviations from mean rank. If such were not the case, there would indeed be little value in knowing which are the best varieties within a given year.

COMPARISON OF HUNDREDTH-ACRE AND TENTH-ACRE PLATS

Comparisons were made of the variation obtained among hundredth-acre plats (hundredths) with that obtained among tenth-acre plats (tenths), using checks in the general variety test plantings and two method-study plantings. Blocks were limited to capacities of 37 plats. The blocks containing the hundredths were therefore only about one-eighth as large as those containing the tenths. The actual area demanded by a hundredth, including its aisle, was about one-eighth that demanded by a tenth including its aisle. Fig. 15 shows the relative sizes of the plats. The hundredths were made by a single 81.7-foot sweep with an 8-hoe drill, and the tenths were made by two 272.3-foot sweeps with a 12-hoe drill.

The fields between which comparisons were made were separated in all cases. When available, more than one block of either plat type was used in a given year and the results averaged. Coefficients of variability are shown, although the standard deviation gave very similar comparisons. The oat data are arranged in Table 12 and the wheat data in Table 13.

TABLE 12.—*Coefficients of variability for two field plat types (hundredths and tenths) in oats.**

Year	1/100 acre	1/10 acre
1910	8.97 (14)	6.24 (20)
1911	9.15 (7)	6.00 (20)
1912	14.84 (14)	4.24 (20)
1913	9.62 (14)	5.64 (20)
1914	5.39 (21)	7.05 (20)
1915	——	13.19 (20)
1916	9.74 (7)	5.49 (20)
1917	——	7.13 (20)
1918	——	3.51 (20)
1919	5.10 (7)	17.99 (20)
1920	——	9.59 (20)
1921	4.05 (7)	5.26 (20)
1922	11.35 (7)	12.14 (20)
1923	——	6.42 (20)
1924	——	9.11 (20)
1925	——	7.57 (50)
1926	8.82 (232)	4.42 (20)
Weighted mean	8.80 (330)	7.69 (370)
Weighted mean (Only paired years)	8.80 (330)	7.45 (200)

*Number of plats in parentheses.

TABLE 13.—*Coefficients of variability for two field plat types (hundredths and tenths) in wheat**

Year	1/100 acre		1/10 acre	
1910	5.74	(14)	6.86	(26)
1911	12.67	(14)	8.45	(26)
1912	18.82	(14)	14.13	(26)
1913	11.36	(14)	4.51	(26)
1914	6.63	(21)	8.25	(26)
1915	7.70	(21)	4.75	(26)
1916	5.99	(14)	5.78	(26)
1917	2.46	(7)	5.47	(26)
1918	4.87	(7)	6.28	(26)
1919	13.17	(7)	5.60	(26)
1920	——		19.17	(26)
1921	9.01	(7)	10.22	(26)
1922	5.42	(7)	6.87	(26)
1923	10.53	(7)	7.13	(26)
1924	12.63	(14)	6.98	(26)
1925	——		10.01	(26)
1926	6.28	(7)	9.84	(20)
Weighted mean	9.17	(175)	8.23	(436)
Weighted mean (Omitting 1920 and 1925)	9.17	(175)	7.37	(384)

*Number of plats given in parentheses.

The high variation in results and lack of close relation between the two columns do not favor a satisfactory interpretation of these tables. By inspection of Table 12 it is seen that among the 10 seasons in which both types were grown, the hundredths were less variable in 4 and the tenths in 6. The matter of prime interest is that, while the tenths show on the whole a somewhat lower variation, they have not demonstrated a decided superiority. If 8.80 is representative of the coefficient of variability for the hundredths in oats that for the means of two distributed should be $\frac{8.80}{\sqrt{2}} = 6.22$. From a labor standpoint the types should probably be compared using about two of the hundredths to one of the tenths. It seems likely that in oats the two hundredth-acre plats will, on the whole, be fully as reliable as one tenth, and in addition will occupy only about one-fourth as much ground.

In Table 13 the hundredths show less variation in 7 of the 15 seasons in which both were grown and the tenths in 8 seasons. Assuming 9.17 to be representative of the coefficient of variability for the hundredths in wheat, the means of two distributed should have a variability of $\frac{9.17}{\sqrt{2}} = 6.49$. As with the oat data, it seems probable that the use of two hundredths has some advantage over a single tenth.

COMPARISON OF HUNDREDTH-ACRE AND FIFTIETH-ACRE PLATS

Fiftieth-acre plats were made by combining adjacent hundredths in the 1926 field method-study oats (Fig. 6). Pairs lying side by side were combined. Blocks of equal plat capacity were used for comparison. Only the Miami plats were used. Results are shown in Table 14.

TABLE 14.—*Standard deviation in bushels per acre of hundredth-acre versus fiftieth-acre field plats compared in blocks of equal plat capacities, field method-study oats, 1926.*

Size of plat	Size of block	Plat capacity of block	Number of blocks studied	Total number of plats	Average S. D. in bushels per acre
1/100 acre	258 feet by 240 feet	82	4	247	6.56
1/50 acre	258 feet by 480 feet	82	2	123	6.16

WIDENED VERSUS LENGTHENED FIELD PLATS

A comparison of the relative effect of adding to the side or end of plats was made using ranges A (east) and A (west) of the 1926 field method-study oats (Fig. 6). Fiftieth-acre plats were made by combining two hundredth-acre plats, first by using pairs lying side by side, and second by using pairs lying end to end. Calculations were made separately for each of the three varieties and the results averaged. The data are shown in Table 15. The results agree in general with those obtained when widened and lengthened nursery plats were compared (Tables 9 and 10).

TABLE 15.—*Standard deviation in bushels per acre of widened versus lengthened fiftieth-acre plats, field method-study oats, 1926.*

Shape of plat	Size of plat	Plat capacity of field	Number of fields studied	Total number of plats	S. D. in bushels per acre
Two drill-widths by 84 feet	1/50 acre	60	1	60	6.52
One drill-width by 174 feet	1/50 acre	60	1	60	6.02

SUMMARY

After an area about 3 rods square had been covered, the size of blocks in small grain nursery plantings at Wooster had but slight influence in increasing the standard deviation of single rod-row plats.

Increasing the size of field tests was accompanied by a slight increase in the standard deviation of the plats where additions were

made which caused the field to approach a square, and by a comparatively large increase where rectangular ranges were extended in length.

Among small grain nursery plats, increasing the length was distinctly more advantageous than increasing the width.

A rapid reduction in standard deviation was found by lengthening single-row nursery plats up to 4 or 5 rods.

No single nursery plat was as reliable as the same area given over to replicated smaller plats. This applies also to field plats.

From two to nearly three single-row, 1-rod plats were needed to attain the same reliability as one single-row, 3-rod plat.

The tendency of 22 wheat varieties to depart from their average ranks over a period of five years was used to compare nursery with field-plat types. The variation from average rank for the field plats was probably not significantly lower than that for the nursery type.

Hundredth-acre and tenth-acre field plats were compared for variation. Considering the difference in size the results seemed to favor the hundredths.

Fiftieth-acre plats were some lower in standard deviation than hundredth-acre plats.

Increasing the size of field plats by adding to the sides was less effective in reducing variation than by increasing the length.

In comparing field-plat types, blocks of equal plat capacities rather than equal area were used.

The formula used for finding the standard deviation was S. D. = $\sqrt{\frac{\Sigma d^2}{n}}$. No correction was made when numbers were small because the populations were made up of plats systematically distributed so as to include the major soil differences.

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COMPOSITION AND ECONOMIC POSSIBILITIES OF THE COTTON BUR[1]

K. S. MARKLEY[2]

INTRODUCTION

For many years the South has been in need of some cheap mechanical means of harvesting the annual cotton crop which has led to the designing and testing of many types of cotton picking devices These include complicated electric pickers, such as the Stukenborg electric cotton picker (1),[3] suction pickers, and the comparatively crude sledding devices (2). It was not until 1926, however, that due to the frosted condition of the Oklahoma crop and the low price of cotton that any considerable portion of the cotton crop was harvested by sledding.

It has been variously estimated (3) that in 1926 one to four million bales of cotton were harvested by sledding and snapping. In this mode of harvesting the whole boll is removed from the cotton plant and sent to the gin where the first process consists in separating the bur from the cottonseed preparatory to ginning. This practice has resulted in an entirely new set of economic conditions for the cotton industry to solve, not the least of which, is the profitable disposal of the burs now being accumulated at the gins in Texas and Oklahoma.[4]

Available statistics indicate that for each bale of cotton sledded, 800 to 900 pounds of burs are removed from the land to accumulate at the gins, one county in Texas producing over 70,000 tons in 1926. The disposal of the burs by means other than burning them at the gins is a pressing problem. The Oklahoma Agricultural and Mechanical College at Stillwater, Oklahoma, and the Texas Agricultural and Mechanical College at College Station, Texas, have begun work on this problem. Fertilizing experiments both with the burs themselves and with the ash obtained by burning them, mulching of potatoes, small fruits, and berries and liquid manure absorption in the feed lot are included in the program. The U. S. Bureau of

[1]Contribution from the Bureau of Standards, Washington, D. C. Publication approved by the Director of the Bureau. Received for publication August 23, 1928.

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[3]Reference by number is to "Literature Cited," p. 1100.

[4]An excellent survey of these problems and the economics involved is given in two articles by Eugene Butler in *Progressive Farmer* (Miss. Valley Ed.), 42: 892 (1927) and (Tex. Ed.) 42: 865 (1927).

Standards was asked to undertake an investigation of this waste product, with the hope that a more profitable utilization might be found than simply burning it.

The burs were kindly furnished by the Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma. As received they were admixed with leaves, stems, immature seeds, and some lint. They were therefore first hand-cleaned and then ground in a Wiley laboratory mill to pass a 0.5 mm mesh sieve before subjecting them to a chemical analysis.

PROCEDURE AND DISCUSSION OF RESULTS

Methods of the Association of Official Agricultural Chemists were used except where otherwise stated. Table 1 gives the proximate analysis of the burs from which it can be seen that they are low in feeding value, although higher in crude fat and protein than cottonseed hull bran. They are, however, lower in nitrogen-free extract and higher in crude fiber than cottonseed hull bran. One use that this analysis suggests is as a diluent for cottonseed and linseed meal. However, it is unlikely that such practice will become general since the burs would have to be ground and transported to the oil mills where cottonseed meal and diluent (the hulls) are produced simultaneously.

TABLE 1.—*Proximate analysis of cotton burs.*

	Air-dry %	Oven-dry %
Moisture	9.82	——
Ash	6.34	7.03
Crude fat	1.84	2.04
Crude protein	6.25	6.93
Crude fiber	42.55	47.18
Nitrogen-free extract	33.20	36.82

In Table 2 is given the percentage of the non-nitrogenous constituents of the burs. The furfural was determined by the Dox and Plaisance (4) thiobarbituric acid method and the pentose and pentosan calculated on the assumption that all the furfural is derived from them. The yield of furfural is very low, being less than half that given by cottonseed hull bran or corn cobs which precludes any possible use of them as a source of this aldehyde.

The extract obtained with 50% ethanol, after clarification, evaporation, etc., gave only a slight copper reduction with Fehling's solution. An aliquot after inversion led to similar results. However, after 2.5 hours hydrolysis with 2.5% hydrochloric acid a copper reduction was obtained equivalent to 22.84% of reducing sugar calcu-

lated as xylose. This figure is about 4% higher than that obtained from the furfural yield. The somewhat higher value is no doubt due to the presence of starch and reducing substances other than pentose.

The lignin content determined by Becker's (5) sulfuric acid treatment is about 1% higher than that of cottonseed hull bran and about that found in normal plant materials, which range from 20 to 30%.

The total cellulose was determined by Sieber and Walter's (6) modified Bevan and Cross chlorination method and α-cellulose by Schorger's (7) α-cellulose method. The total cellulose figure agrees well with that for the crude fiber in spite of the fact that it has not been corrected for ash, lignin, and pentosan which would bring the value somewhat below the crude fiber value. The cellulose yield is not unduly low and compares favorably with the principle American woods used as sources of cellulose which range from 50 to 60% and higher.

TABLE 2.—*Non-nitrogenous constituents of cotton burs.*

	Air-dry %	Oven-dry %
Furfural	10.87	12.05
Furfural expressed as pentose	16.98	18.83
Furfural expressed as pentosan	14.94	16.57
Dextrose (alcoholic-extract)	trace	——
Sucrose (alcoholic-extract)	——	——
Reducing sugar after hydrolysis expressed as dextrose	20.25	22.46
Reducing sugar after hydrolysis expressed as xylose	20.60	22.84
Lignin	22.27	24.70
Total cellulose	42.8*	47.4*
α-cellulose	29.9*	33.1*

*Cellulose analysis kindly furnished by Walter T. Schreiber.

In order to obtain an ash comparable with that produced at the gins, 150 grams of burs were ashed without previous hand-cleaning and the mineral or fertilizing constituents determined. The results for the ash and the oven-dry burs are given in Table 3. The values for the burs were obtained by multiplying the ash constituent values by 7.18. Manganese and carbon dioxide were present but were not determined due to insufficient quantity of ash prepared. The removal of such large amounts of mineral fertilizing constituents tends to deplete the soil and should be replaced by mixed fertilizers or the bur ash itself, in order that the present productivity of the soil be maintained. One method of doing this would be to subject the collected burs to artificial manure production by bacterial action such as has been done with wheat straw (8), rice straw (9), cane trash (10), and other plant residues. This might be done either on the farm or at the gins and the resulting manure returned to the land. Such a

practice would return to the soil practically all of the mineral constituents, together with a considerable amount of humus without the deleterious effect upon nitrate accumulation which accompanies ordinary cellulose decomposition in the soil.

TABLE 3.—*Mineral constituents of the ash of cotton burs.*

	Ash %	Oven-dry burs %
SiO_2	15.95	1.15
R_2O_3	4.82	0.35
CaO	9.93	0.71
MgO	5.75	0.41
Na_2O	11.25	0.81
K_2O	33.20	2.38
P_2O_5	4.10	0.29
SO_3	3.79	0.27
Cl	2.11	0.15

CONCLUSIONS

Analyses of cotton burs produced in the snapping or sledding methods of harvesting cotton show that they do not possess a high feeding value for cattle without some form of hydrolytic treatment, such as has been proposed for increasing the digestibility of cottonseed hulls. They have no value as a source of furfural. The pentosan content is quite low, but they possess a content of cellulose which might possibly make them valuable as a source of pulp for paper, rayon, etc. That large quantities of inorganic fertilizer constituents are removed from the soil is evident from the ash analysis. This deficiency should be repaired either by application of artificial fertilizer or by returning the burs to the soil. The latter may be done either in the form of the ash, the whole burs, or preferably, by the artificially decomposed burs.

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COMPOSITION OF COTTONSEED HULL BRAN[1]

K. S. Markley[2]

INTRODUCTION

The problem of a profitable utilization of cottonseed hulls dates back to the beginning of the cottonseed oil industry (ca 1870) and has become more important yearly because of the continually increasing production of cottonseed oil. Wesson (1)[3] estimates that in modern oil mill practice there are produced 375 pounds of hulls for every ton of seed crushed and that 6.5 million tons of seed find their way to the mills annually. This means that about 1.25 million tons of hulls are produced annually (2) the profitable utilization of which is a problem of no small economic importance to the cotton oil industry, and indirectly, to the farmer.

The product obtained from cottonseed hulls after removal of the lint and grinding is termed cottonseed hull bran, new uses for which are being sought and wider markets desired. Since a thorough knowledge of the composition of cottonseed hull bran was thought to be desirable before any semi-commercial work was attempted, the Bureau of Standards undertook a study of its composition with the results reported below. The particular product investigated was furnished by the East St. Louis Cotton Oil Company, and, according to the information supplied the author, the material had been previously ground and the major portions of the fibers removed by an air separation process. As received, the bran contained only a very small amount of short fiber which could be separated by further sieving. This, however, was not thought to be desirable and the bran was therefore analyzed as received.

PROCEDURE AND DISCUSSION

The methods used in this investigation were those of the Association of Official Agricultural Chemists (Edition 2), except where otherwise indicated. For the sake of convenience the results are presented in four tables, but they are best discussed as a whole.

That the bran is low in feeding value is evident from a consideration of Table 1, which indicates that it is composed primarily of the so-called nitrogen-free extract and crude fiber. The nitrogen-

[1]Contribution from the National Bureau of Standards, Washington, D. C. Publication approved by the Director of the Bureau. Received for publication September 14, 1928.

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[3]Reference by number is to "Literature Cited", p. 1107.

free extract fraction is generally supposed to consist of sugars, starch, pentosans, organic acids, and the more soluble portion of the cellulose, while the crude fiber consists essentially of the more stable cellulose.

TABLE 1.—*Proximate analysis of cottonseed hull bran.*

	Air-dry %	Oven-dry %
Moisture	12.25	——
Ash	2.09	2.38
Crude fat	0.80	0.91
Crude protein	2.88	3.28
Crude fiber	32.48	37.01
Nitrogen-free extract	49.50	56.42

The composition of these fractions becomes clearer upon consideration of Table 2. The yield of furfural is quite unusual, amounting as it does to more than one-fourth of the dry weight of the bran. This figure is higher than that recorded in the literature for most woods, cereal straws, corn cobs, and stalks, and such grain hulls as those of oats and rice. The yield of furfural most closely approaching that from cottonseed hull bran is that from corn cobs for which Sweeney (3) records values of 21.04 to 23.61%. Commercially, furfural is produced from oat hulls rather than from corn cobs because of the better segregation of the former. Cottonseed hulls from which the bran is produced are equally well segregated and are lower in feeding value and higher in furfural-yielding constituents, thereby making them a particularly attractive source of this aldehyde. The pentose and pentosan values recorded in Table 2 are calculated from the furfural yield by means of Kröber's formulae.

TABLE 2.—*Non-nitrogenous constituents of cottonseed hull bran.*

	Air-dry %	Oven-dry %
Furfural	22.23	25.33
Furfural expressed as pentose	43.21	49.24
Furfural expressed as pentosan	38.02	43.33
Dextrose		
50% alcoholic extract	trace	——
Sucrose		
50% alcoholic extract	none	——
Galactose	present	——
Reducing sugar after hydrolysis cal'ated as dextrose	37.59	42.84
Reducing sugar after hydrolysis calc'lated as xylose	38.24	43.58
Crude cellulose	45.36	51.7
Lignin	20.91	23.83

Extraction of the bran with hot 50% alcohol gave only a trace of reducing sugar when the extract was tested with Fehling's solution. An aliquot of the same extract after inversion with hydrochloric

acid likewise gave negative results. Three 1-gram samples, after hydrolysis with boiling 2.5% hydrochloric acid for 2½ hours, gave a copper value equivalent to 42.84% dextrose on the basis of the oven-dry material. If the dextrose figure is calculated to xylose by the relation $\frac{\text{dextrose}}{\text{xylose}} = 0.983$, a value for xylose of 43.58% is obtained. The hydrolysis under the above condition is practically complete, as will be shown later. This is rather remarkable in view of the fact that Hudson and Harding (4), hydrolyzing cottonseed hulls with boiling 7% sulfuric acid, isolated only 8 to 12% crystalline xylose; while Sherrard and Blanco (5), using 1.8 to 2.5% sulfuric acid at 100 to 120 pounds pressure, obtained only 9.6 to 16.7% of reducing sugar.

Galactose appears to be present in small amounts, but a quantitative estimation by means of its oxidation to mucic acid does not seem to be possible. Every attempt to separate the mucic acid in pure form failed, due to the presence of a contaminating gelatinous material.

The three values, namely, nitrogen-free extract, 56.42%, pentose, 49.24%, and reducing sugar expressed as xylose, 43.58%, are not in absolute agreement with one another, but all indicate a high content of non-cellulosic carbohydrate (reducing sugar). That these values do not agree is to be expected. The nitrogen-free extract contains a certain proportion of the more soluble cellulose. The pentose is calculated on the assumption that all of the furfural is derived from it, which is probably incorrect.

The possibility of furfural production from lignin, uronic acids, such as glucuronic and xyluronic, and other aldehydic substances, is not excluded. In fact, at least one of these sources appears to be indicated from the results given below. For similar reasons the value obtained for xylose is probably not exact, since the presence of hexoses, other pentoses, such as arabinose, and aldehydic acids, such as the uronic acids, would likewise reduce Fehling's solution. In other words, we are dealing with a mixture of sugars and other reducing substances and no single factor can be of service in relating the copper value to sugar content. At the present time efforts are being made to determine the best method of preparing xylose in quantity from cottonseed hull bran, the results of which will be reported in a later paper.

It might be stated here that in preliminary experiments yields of pure crystalline xylose exceeding 12% by weight of the air-dry bran have been obtained by one crystallization. Should commercial production of xylose from cottonseed hulls or cottonseed hull bran

be undertaken, it would be necessary to hydrolyze with dilute sulfuric acid instead of hydrochloric acid as the removal of hydrochloric acid from the hydrolysate before evaporation to a syrup would be impracticable.

The crude cellulose was determined by Sieber and Walter's (6) modification of the Bevan and Cross chlorination method; the alpha-cellulose by Schorger's (7) alpha-cellulose method; and lignin by Becker's (8) sulfuric acid treatment. The composition of the Cross and Bevan cellulose is given in Table 3. It is surprising that, although the total Cross and Bevan cellulose amounts to approximately 52% of the oven-dry bran, the alpha-cellulose content is only about 24%.

TABLE 3.—*Composition of the Cross and Bevan cellulose.*

	Crude cellulose %	Cottonseed hull bran Air-dry %	Cottonseed hull bran Oven-dry %
		45.55	51.91
Ash	0.42	0.19	0.22
Pentosan	36.17	16.48	18.78
Alpha-cellulose*	45.65	20.79	23.70
Beta-cellulose	15.3	6.97	7.94

*Uncorrected for pentosan and ash. Corrected value equals 43.97%.

Table 4 presents the results obtained in the study of the source of the furfural reported in Table 2. In the latter determinations recourse was had to the thiobarbituric acid method described by Dox and Plaisance (9), because this method gives more concordant results than the official phloroglucinol method. The hydrolysate referred to in Table 4 is an aliquot of the same solution used for determining the reducing sugars. One hundred cc aliquots of the 2.5% hydrochloric acid hydrolysate were made up to 12% with strong hydrochloric acid and distilled as usual for furfural. The residue from the 2.5% hydrolysis was also distilled with 12% hydrochloric acid and the furfural yield determined. The total of these two values practically equals that obtained by direct distillation of the original bran. This constitutes the evidence, referred to above, that 2.5% hydrochloric acid produces practically complete hydrolysis. It does not, however, prove that the furfural is all derived from xylose or pentoses in general.

An effort was made to isolate pure lignin from cottonseed hull bran by extraction with cold 2% alcoholic sodium hydroxide, according to the method outlined by Phillips (10). Besides lignin, there was extracted a dark red pigment to which the cottonseed hull

bran apparently owes its characteristic red-brown color. When the extract was made neutral to litmus and concentrated in vacuo most of the pigment separated as a gummy precipitate, very difficult to remove by filtration. After drying it was found to be insoluble in cold absolute alcohol, ether, and acetone. It was slowly soluble in 0.1 N sodium hydroxide, quite soluble in 10% sodium hydroxide and in boiling water, but could not be reprecipitated on addition of hydrochloric acid. Distilled with 12% hydrochloric acid, it gave 17.42% of furfural equivalent to 23.95% of pentosan.

When the bran itself was extracted with hot water, the extract gave a slight brownish-green precipitate with ferric chloride and a slight brownish precipitate with lead acetate. Bromine, lime water, and 3% sodium chloride, plus 1% gelatine solution, gave no reaction. This would indicate that tannin and phlobophene were absent and that the pigment was primarily a xylan body.

The lignin was precipitated with an excess of hydrochloric acid after separation of the pigment referred to above. Instead of separating as a yellow oil, as reported by Phillips with corn cobs, it separated as a non-settling, fluocculant, reddish material. Phillips found that his lignin gave no trace of furfural upon prolonged distillation with 12% hydrochloric acid, whereas that from cottonseed hull bran gave 8.15% of furfural. It is possible, due to the physical condition of the separated lignin, that some of the red pigment may have been occluded. However, further work will be necessary before any definite conclusions can be drawn, and this is difficult due to the lack of knowledge of the constitution, or of any criteria for the purity, of lignin.

TABLE 4.—*Furfural by the thiobarbituric acid method.*

Source of the furfural	Air-dry %	Oven-dry %
2.5% HCl hydrolysate	22.28	25.39
Residue from hydrolysis	0.93	1.06
Total	23.21	26.45
Original material	22.96	26.17
Lignin	——	8.15
Pigment	——	17.42

CONCLUSIONS

Extensive analytical data on cottonseed hull bran are presented above. It is hoped that a better understanding of the constituents composing cottonseed hull bran thus obtained will lead to finding a more profitable outlet for this by-product of the cottonseed oil mills. The furfural yield is exceptionally high. Xylose, plus other

pentoses, amounting to about 40%, and a crude cellulose content of 51% all indicate that cottonseed hull bran is a more valuable product than was heretofore thought to be the case.

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A BIOMETRICAL STUDY OF FACTORS AFFECTING YIELD IN OATS[1]

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INTRODUCTION

Yield and quality are two of the most important characters with which the plant breeder is concerned. These two characters are the result of the interaction of various environmental and genetic factors. It is often very difficult or even impossible to isolate these factors and study the comparative value of each in relation to yield or quality except by the use of biometrical analyses.

The most useful statistical constant with which to measure the relationship between two characters is the coefficient of correlation. According to Fisher (1),[3] "No quantity is more characteristic of modern statistical work than the correlation coefficient, and no method has been applied successfully to such various data as the method of correlation." While ultimate causes cannot be measured by the use of correlation coefficients, the effect of specific causes is readily determined. In studying the inter-relationships between a number of characters, the method of partial correlations furnishes an important biometrical tool whereby a more nearly correct relationship between two characters can be determined than from the simple product moment coefficients of correlation. In fact, when several characters are inter-related deductions based on simple or zero order correlation coefficients are often misleading.

Goulden and Elders (2), from a study of the characters of wheat varieties influencing yield, found that date of heading and reaction to stem rust were most highly correlated with yield, as determined from a partial correlation study. They found negative correlations also between yield and leaf rust and yield and weakness of straw.

Hayes, Aamodt, and Stevenson (3) found that plumpness of seed, stem and leaf rust, and height of plants were associated with yield of spring wheats; and that plumpness, stem rust, date heading, height, and winter injury were associated with yield of winter wheats. A study was made by means of multiple correlation coefficients to determine the total effect on yield or quality of these factors.

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[3]Reference by number is to "Literature Cited," p. 1119.

Quisenberry (7), from samples of wheat taken from farmers' fields in Oklahoma, Kansas, Nebraska, and Montana, found that the number of heads per unit area was one of the most important factors determining yield, closely followed by number of kernels per head. Weight per 1,000 kernels was not as important in determining yield as the other two characters mentioned. The relationships of these characters to one another were studied by means of both simple and partial correlation coefficients.

This study was undertaken chiefly for the purpose of determining the importance of various factors in relation to yield of oats grown at University Farm, Waseca, Crookston, and Morris, Minnesota, and also to determine if the same strains of oats would react in the same way under different environmental conditions.

MATERIALS AND METHODS

The strains of oats used in this study were grown in rod-row trials and were obtained from double crosses of Black Mesdag, which is immune from attacks of both loose and covered smut, with homozygous selections from crosses of Minota x White Russian and Victory x White Russian, which were resistant to black stem rust. The lines selected were immune from smut and resistant to stem rust. The final selections for the rod-row trials were made in the F_5 generation from lines which appeared homozygous. Studies of inheritance and methods of breeding by means of which the strains were obtained have been reported by Hayes, et al (4). The breeding studies were under the general direction of Dr. Hayes who suggested the desirability of the present study.

While selection had been made for desirable plants from promising appearing lines during the F_2 to F_4 segregating generations, no data had been taken previously on yield, and no accurate estimate of the desirability of individual strains was possible. Two hundred and eighty strains were grown at University Farm in three systematically distributed rod-row plats of three rows each and 38 other strains were grown in three systematically distributed single-row plats at University Farm, and at the three branch stations of Waseca in southern Minnesota, Morris in west central Minnesota, and Crookston in northwestern Minnesota, in 1927.

Notes were taken on yield, plumpness, date heading, height, crown rust (*Puccinia coronata*, Cda.), lodging, and blast. The averages of these characters from the three plats of each strain were obtained and these averages used in this study. Yield was expressed in bushels per acre, plumpness in per cent, date heading in

days, height in inches, and crown rust in per cent. The lodging index was obtained by multiplying the percentage lodged by the degree lodged and the notes on blast or spikelet blight were arbitrarily taken in the four classes of 0, 1, 2, and 3.

Notes were obtained at University Farm on the seven characters mentioned and on all these characters except blast at Waseca. Blast was recorded at University Farm only. At Crookston, notes on date heading were not obtained on all strains and lodging was so severe that the notes for this character were of no use. At Morris, there was no appreciable lodging and date of heading and crown rust notes were not secured.

In this study, the term total correlation coefficient is used to designate the zero order or simple correlation coefficients. The partial correlation coefficient is used to express the relationship between two characters holding constant one or more other variables. Multiple correlation coefficients are those measuring the influence of several independent variables on a single dependent variable. Partial multiple correlation coefficients measure the effect of two or more variables on a dependent variable holding constant still other variables. All calculations in this study were carried out uniformly to four places of decimals. In presenting the data, however, only two decimal places are given in keeping with Kelley's (6) suggestion regarding the number of significant places. In calculating the probable errors of the total correlation coefficients, the formula $P. E._r = 0.6745 \frac{1 - r^2}{\sqrt{N-1}}$, where N = the total frequency, was used. Unity was subtracted from N for each variable eliminated in calculating the probable errors of the partial correlation coefficients following the method used by Fisher (1).

EXPERIMENTAL RESULTS

In a biometrical study, it is of considerable interest to know the range of variability of each character. It is obvious that if a study is made of material which has been selected previously that the range of variability will be smaller than for unselected material. Correlation studies will be of little value in determining the relation between particular characters when variability has been reduced by selection. While selection for certain of the characters studied in this paper was made during the segregating generations, no material had been eliminated as a result of careful replicated trials such as rod-row tests.

RESULTS WITH 280 STRAINS OF OATS AT UNIVERSITY FARM

In Table 1 is presented the mean, standard deviation, and range in variability of each of the seven characters to be considered in this phase of the study. It will be seen that the yields of the different strains of oats ranged from 20.8 to 79.5 bushels per acre. The variability of the other characters with the exception of blast was also large.

TABLE 1.—*Characters of 280 oat strains grown at University Farm with the mean, standard deviation, and range of variability of each character.*

Character	Symbol	Mean	σ	Range in variability
Yield	Y	45.97 ± .39	9.63 ± .27	20.8— 79.5 bushels
Plumpness	P	23.63 ± .70	17.39 ± .50	0— 68%
Date heading	D	6.24 ± .08	2.09 ± .06	July 3 — July 12
Height	H	40.31 ± .07	1.72 ± .05	35— 45 inches
Crown rust	R	35.27 ± .61	15.21 ± .43	5— 70%
Lodging	L	71.83 ± .86	21.32 ± .61	0— 98
Blast	B	1.59 ± .02	0.49 ± .01	0.7— 3.0

All possible inter-relationships between the six characters of yield, plumpness of grain, date of heading, height of plants, reaction to crown rust, and amount of lodging were determined by means of the product moment coefficients of correlation and by partial correlation coefficients. The results are given in Table 2.

TABLE 2.—*Total and partial correlation coefficients for inter-relations of various characters of 280 strains of oats grown at University Farm in 1927.*

Total correlation coefficients		Partial correlation coefficient*	
Yield and plumpness	= +.78 ± .02	$r_{YP.DHRL}$	= +.50 ± .03
Yield and date heading	= —.56 ± .03	$r_{YD.HLR}$	= —.72 ± .02
Yield and height	= —.09 ± .04	$r_{YH.DRL}$	= +.02 ± .04
Yield and crown rust	= —.17 ± .04	$r_{YR.DHL}$	= —.49 ± .03
Yield and lodging	= —.21 ± .04	$r_{YL.DHR}$	= —.48 ± .03
Yield and blast	= —.08 ± .04	$r_{YB.D}$	= +.02 ± .04
Plumpness and date heading	= —.49 ± .03	$r_{PD.HRL}$	= —.70 ± .02
Plumpness and height	= —.05 ± .04	$r_{PH.DRL}$	= +.07 ± .04
Plumpness and crown rust	= —.17 ± .04	$r_{PR.DHL}$	= —.48 ± .03
Plumpness and lodging	= —.32 ± .04	$r_{PL.DHR}$	= —.58 ± .03
Date heading and height	= +.31 ± .04	$r_{DH.RL}$	= +.24 ± .04
Date heading and crown rust	= —.30 ± .04	$r_{DR.HL}$	= —.23 ± .04
Date heading and lodging	= —.19 ± .04	$r_{DL.HR}$	= —.22 ± .04
Height and crown rust	= —.33 ± .04	$r_{HR.DL}$	= —.25 ± .04
Height and lodging	= +.01 ± .04	$r_{HL.DR}$	= +.05 ± .04
Crown rust and lodging	= —.04 ± .04	$r_{RL.DH}$	= —.09 ± .04

*Where Y = yield, P = plumpness, D = date heading, H = height, R = crown rust, L = lodging, and B = blast.

The character plumpness of seed was strongly correlated with yield in 1927 as shown by the total correlation coefficient of $+.78 \pm .02$. Even when the effects of date of heading, height, crown rust, and lodging were held constant the correlation between yield and plumpness, $r_{YP.DHRL}$, was $+.50 \pm .03$. The total correlation $r_{YP} = +.78 \pm .02$ is a measure of the extent that observed notes on plumpness were relevant information regarding yield. The partial correlation $r_{YP.DHRL} = +.50 \pm .03$ measures the extent to which a knowledge of plumpness would furnish information regarding yield if the effects of date heading, height, rust, and lodging were held constant. Hayes, et al (3) found plumpness of seed a valuable index to yield in wheat and pointed out the value of selecting plump-seeded plants during the segregating generations. A similar result was obtained in these oat studies where plumpness of seed as a strain characteristic was strongly correlated with yield.

The relationship between yield and date heading was strongly negative, $r_{YD} = -.56 \pm .03$, indicating that early oats yielded far more than later oats at University Farm in 1927. In some seasons early oats give the best yields and in others late oats prove superior at University Farm. When the effects of height, crown rust, and lodging were held constant, this correlation increased to $r_{YD.HRL} = -.72 \pm .02$. By holding constant the effects of height, crown rust, and lodging on yield and date heading a more accurate measure of the true relationship between these two variables alone is obtained than is obtained from the simple correlation coefficient, where the influence of these disturbing factors was not controlled. In this case crown rust was one of the characters chiefly responsible for disturbing the true relationship between the two characters yield and date heading, $r_{YD.R}$ being $-.64 \pm .02$. The partial regression, $\beta_{YD.HRL}$, of yield on date heading with height, crown rust, and lodging held constant, was 3.01. Assuming that $\beta_{YD.HRL}$ measured the true relationship between yield and date heading, it could be said that on the average for every day that date heading was delayed the yield was reduced by 3 bushels per acre. The strains heading on July 12 yielded 27 bushels less than those heading on July 3 because of their later heading date.

The crown rust epidemic of 1927 was the most severe experienced in Minnesota in recent years. The true relationship between the two characters yield and crown rust could not be determined from the total correlation coefficients, due, very largely, to the disturbing influence of date heading. The strains heading first tended to yield the most but were also most heavily rusted. Therefore, when the disturbing

influence of date heading, which was largely responsible for the pseudo-relationship reflected in the total correlation of yield and crown rust, was held constant, the correlation coefficient mounted from $r_{YR} = -.17 \pm .04$ to $r_{YR.D} = -.42 \pm .03$ and, when height and lodging were also held constant, $r_{YR.DHL} = -.49 \pm .03$. When the effects of date heading, height, and lodging, largely of date heading, were eliminated, a more accurate experiment regarding the effect of crown rust on yield was obtained. In this case the partial regression of yield on crown rust with height, date heading, and lodging held constant was $-.32$. Assuming as before that $\beta_{YR.DHL}$ measured the true relationship between yield and crown rust, it could be said that on the average an increase of 1% in crown rust resulted in a reduction in yield of 0.32 bushel per acre. Since some of the lines were rusted 65% more than others, it could be said that yields of the most susceptible lines were reduced 20 bushels per acre by crown rust, when compared with the most resistant strains. Breeding for crown rust resistance assumes a position of considerable importance when conditions such as these are encountered.

Lodging affected yield to a considerable extent. When date heading, height, and crown rust were held constant, the partial correlation between yield and lodging was $r_{YL.DHR} = -.48 \pm .03$ which is significantly larger than the total correlation $r_{YL} = -.21 \pm .04$.

Neither height of plants nor blast were associated significantly with yield, as measured by the total correlations which are about twice their probable errors or by the partial correlation coefficients, both $r_{YH.DRL}$ and $r_{YB.D}$ being $+.02 \pm .04$.

The inter-relationships between date heading, height, crown rust, and lodging, as measured by the total correlation coefficients were not materially changed by holding constant the other two of these four variables in a partial correlation coefficient. The true relationship between these four characters was very accurately measured by the total correlation coefficients.

The multiple correlation coefficient of yield with plumpness, date heading, height, crown rust, and lodging was $.82 \pm .01$. With $R_{Y.PDHRL} = .82 \pm .01$, it may be said that 67% ($R^2 = .67$) of the total squared variability in yield could be explained in terms of its mathematical relation to the factors included in this formula, leaving 33% unexplained (5). When the character plumpness was omitted from the multiple correlation, $R_{Y.DHRL} = .75 \pm .02$. In this case $R^2 = .56$, or it may be said that the four characters date heading, height, crown rust, and lodging accounted for 56% of the squared variability in yield. The multiple effect of date heading, height,

crown rust, and lodging on plumpness was found to be the same as their effect on yield, $R_{P.DHRL} = .76 \pm .02$.

The relationship of the disease crown rust with yield with the three agronomic characters date heading, height, and lodging held constant was given by the partial correlation $r_{YR.DHL} = -.49 \pm .03$. The effect of these three agronomic characters on yield with crown rust held constant was given by the multiple partial correlation coefficient $R_{Y.DHL/R} = .74 \pm .02$ (8),[4] which means the total correlation of Y with D, H, and L with R held constant. The total effect of date heading and crown rust on yield was given by the coefficient $R_{Y.DR} = .66 \pm .03$. With height and lodging held constant, $R_{Y.DR/HL}$ became $.74 \pm .02$. This is essentially the same as $R_{Y.DHRL} = .75 \pm .02$ and $R_{Y.DHL/R} = .74 \pm .02$. This would mean that when height and lodging were held constant the factors date heading and rust accounted for the same amount of variability in yield as did all four factors combined.

As an illustration of the difference in results that are obtained by using selected material rather than a random sample of the entire

TABLE 3.—*Correlation coefficients between characters in 139 strains of oats with rust reaction from 5 to 35%, 141 strains with rust reaction from 35 to 70%, and the entire 280 strains combined.*

Total correlation coefficients		Partial correlation coefficients*	
Lines with rust between 5 and 35%			
Yield and date heading	$= -.65 \pm .03$	$r_{YD.RL}$	$= -.72 \pm .03$
Yield and crown rust	$= -.26 \pm .05$	$r_{YR.DL}$	$= -.11 \pm .06$
Yield and lodging	$= -.15 \pm .06$	$r_{YL.DR}$	$= -.45 \pm .05$
Date heading and crown rust	$= +.15 \pm .06$	$r_{DR.L}$	$= +.22 \pm .05$
Date heading and lodging	$= -.31 \pm .05$	$r_{DL.R}$	$= -.35 \pm .05$
Crown rust and lodging	$= +.19 \pm .06$	$r_{RL.D}$	$= +.25 \pm .05$
Lines with rust between 35 and 70%			
Yield and date heading	$= -.58 \pm .04$	$r_{YD.RL}$	$= -.66 \pm .03$
Yield and crown rust	$= -.03 \pm .06$	$r_{YR.DL}$	$= -.16 \pm .06$
Yield and lodging	$= -.28 \pm .05$	$r_{YL.DR}$	$= -.47 \pm .04$
Date heading and crown rust	$= -.10 \pm .06$	$r_{DR.L}$	$= -.11 \pm .06$
Date heading and lodging	$= -.14 \pm .06$	$r_{DL.R}$	$= -.15 \pm .06$
Crown rust and lodging	$= -.06 \pm .06$	$r_{RL.D}$	$= -.08 \pm .06$
All lines combined			
Yield and date heading	$= -.56 \pm .03$	$r_{YD.RL}$	$= -.73 \pm .02$
Yield and crown rust	$= -.17 \pm .04$	$r_{YR.DL}$	$= -.50 \pm .03$
Yield and lodging	$= -.21 \pm .04$	$r_{YL.DR}$	$= -.48 \pm .03$
Date heading and crown rust	$= -.30 \pm .04$	$r_{DR.L}$	$= -.31 \pm .04$
Date heading and lodging	$= -.19 \pm .04$	$r_{DL.R}$	$= -.22 \pm .04$
Crown rust and lodging	$= -.04 \pm .04$	$r_{RL.D}$	$= -.11 \pm .04$

*Where Y = yield, D = date heading, R = crown rust, and L = lodging.

[4] $1-R^2_{Y.DHL/R} = \dfrac{1-R^2_{Y.DHRL}}{1-R^2_{YR}}$.

population, correlation coefficients for the different inter-relationships of the characters in 139 strains of oats with less than 35% crown rust and again with 141 strains with more than 35% of rus were calculated separately. These relationships were compared with those obtained when all of this material was combined. The results are given in Table 3.

The partial correlation coefficient between yield and crown rust for the strains with less than 35% rust with constant date heading and lodging was —.11 ±.06. The same coefficient, $r_{YR.DL}$, for the strains with more than 35% rust, was —.16 ±.06. When both of these groups of strains were combined the same partial correlation coefficient became —.50 ±.03. The same condition was found in considering the relationship between rust and date heading. In the more or less crown rust resistant strains $r_{DR.L}$ = +.22 ±.05, in the susceptible strains $r_{DR.L}$ = —.11 ±.06, and when both groups were combined this correlation coefficient became —.31 ±.04. This emphasizes the errors which may be encountered when biometrical studies are made on material from which certain classes have been eliminated by selection. In the strains with less than 35% rust $R_{Y.DRL}$ = .75 ±.03, in the strains with more than 35% rust $R_{Y.DRL}$ = .70 ±.03, and when all strains were combined this multiple correlation coefficient became .75 ±.02. It would appear that the same amount of variability in yield, as shown by the multiple R, was accounted for whether the grouping for rust reaction was made or not.

RESULTS WITH 38 STRAINS OF OATS GROWN AT UNIVERSITY FARM, WASECA, CROOKSTON, AND MORRIS

Thirty-eight strains of oats which seemed most desirable as judged from notes taken on the plant rows in F_5 were grown at University Farm and at the branch experiment stations at Waseca, Crookston, and Morris in 1927. The total correlation coefficients between the characters in these four localities are given in Table 4.

The correlations between yield and plumpness were high in all four localities. The same general relationships as expressed by the total correlations existed between the different characters in all comparisons except where yield or plumpness were correlated with date heading or crown rust. These were quite different in the different localities.

The correlations of yield with plumpness or date heading were not significantly different at University Farm, Waseca, or Crookston.

TABLE 4.—*Total correlation coefficients between various factors affecting yield in 38 strains of oats grown at University Farm, Waseca, Crookston, and Morris in 1927.*

Characters correlated	University Farm	Waseca	Crookston	Morris
Yield and plumpness	+.89±.02	+.77±.05	+.78±.04	+.58±.07
Yield and date heading	—.58±.07	—.16±.11	—.26±.10	———
Yield and height	+.01±.11	+.30±.10	———	+.24±.10
Yield and crown rust	—.23±.11	—.48±.09	—.39±.09	———
Yield and lodging	—.24±.10	—.26±.10	———	———
Plumpness and date heading	—.57±.07	—.32±.10	—.25±.10	———
Plumpness and height	+.02±.11	+.09±.11	———	+.08±.11
Plumpness and crown rust	—.11±.11	—.27±.10	—.43±.09	———
Plumpness and lodging	—.30±.10	—.31±.10	———	———
Date heading and height	+.39±.09	+.34±.10	———	———
Date heading and crown rust	—.29±.10	—.38±.09	—.36±.10	———
Date heading and lodging	+.10±.11	—.23±.11	———	———
Height and crown rust	—.41±.09	—.53±.08	———	———
Height and lodging	+.33±.10	—.04±.11	———	———
Crown rust and lodging	—.19±.11	+.26±.10	———	———

Crown rust was correlated with yield to relatively the same degree at University Farm, Waseca, and Crookston. The other partial correlation coefficients at University Farm and Waseca were approximately the same.

The multiple correlation coefficient of yield with plumpness, date heading, height, crown rust, and lodging in these 38 strains grown at University Farm was $R_{Y.PDHRL}$ = .91 ±.02. This was slightly higher than a similar multiple correlation coefficient of $R_{Y.PDHRL}$ = .82 ± .01 calculated for 280 strains of oats grown under the same conditions. An $R_{Y.PDHRL}$ = .91 ± .02 would mean that 83%

TABLE 5.—*Partial correlation coefficients between various characters affecting yield in 38 strains of oats grown at University Farm, Waseca, Crookston, and Morris in 1927.*

University Farm		Waseca		Crookston	
$r_{YP.DHRL}$*	= +.75±.05	$r_{YP.DHRL}$	= +.67±.06	$r_{YP.DR}$	= +.66±.06
$r_{YD.HRL}$	= —.75±.05	$r_{YD.HRL}$	= —.48±.09	$r_{YD.R}$	= —.47±.09
$r_{YH.DRL}$	= +.31±.10	$r_{YH.DRL}$	= +.18±.11		———
$r_{YR.DHL}$	= —.52±.08	$r_{YH.DRL}$	= —.47±.09	$r_{YR.D}$	= —.54±.08
$r_{YL.DHR}$	= —.44±.09	$r_{YL.DHR}$	= —.28±.11		———
$r_{DH.RL}$	= +.30±.10	$r_{DH.RL}$	= +.19±.11		———
$r_{DR.HL}$	= —.16±.11	$r_{DR.HL}$	= —.20±.11		———
$r_{DL.HR}$	= —.05±.11	$r_{DL.HR}$	= —.17±.11		———
$r_{HR.DL}$	= —.30±.10	$r_{HR.DL}$	= —.48±.09		———
$r_{HL.DR}$	= +.29±.10	$r_{HL.DR}$	= +.15±.11		———
$r_{RL.DH}$	= —.07±.11	$r_{RL.DH}$	= +.24±.11		———

*Y = yield, P = plumpness, D = date heading, H = height, R = crown rust, and L = lodging.

of the total squared variability in yield could be explained in terms of the mathematical relations between yield and the other five characters considered in this formula. When the factor plumpness was omitted from the multiple correlation the coefficient $R_{Y.DHRL} = .79 \pm .04$. In the Waseca test the multiple correlation coefficients were slightly smaller, $R_{Y.PDHRL} = .83 \pm .03$ and $R_{Y.DHRL} = .65 \pm .06$. At Crookston $R_{Y.PDR} = .79 \pm .04$ and $R_{Y.DR} = .58 \pm .07$ were obtained.

In Table 6 are given the total correlation coefficients between the same characters of these 38 strains of oats grown at University Farm and the three branch experiment stations.

TABLE 6.—*Total correlation coefficients between the same character of 38 strains of oats grown in different localities in 1927.*

	Total correlation of		
	Yield	Plumpness	Date heading
University Farm and Waseca	+.61±.07	+.71±.06	+.85±.03
University Farm and Crookston	+.66±.06	+.63±.07	+.78±.04
University Farm and Morris	+.30±.10	+.54±.08	———
Waseca and Crookston	+.58±.07	+.61±.07	+.84±.03
Waseca and Morris	+.81±.04	+.63±.07	———
Crookston and Morris	+.38+.09	+.32+.10	———
	Height	Crown rust	Lodging
University Farm and Waseca	+.60±.07	+.62±.07	+.16±.11
University Farm and Crookston	———	+.47±.09	———
University Farm and Morris	+.46±.09	———	———
Waseca and Crookston	———	+.56±.08	———
Waseca and Morris	+.58±.07	———	———
Crookston and Morris	———	———	———

Except for the character lodging these 38 strains responded in a quite similar manner at University Farm, Waseca, and Crookston. The yields at Morris were not, however, very closely associated with the yields at either University Farm or at Crookston, as measured by the total correlation coefficient. Apparently different factors influenced yields at Morris than at University Farm or Crookston.

Date of heading in one locality would be expected to be highly correlated with date heading of the same strains grown in another locality. Such was found to be the case, correlation coefficients of $+ .85 \pm .03$, $+ .78 \pm .04$, and $+ .84 \pm .03$ being obtained. Height of plants was found to be influenced more by environmental conditions than date heading, as shown by the lower correlation coefficients between height in different localities. Correlation coefficients of $+ .62 \pm .07$, $+ .47 \pm .09$, and $+ .56 \pm .08$ for crown rust reaction of the same strains of oats grown in quite widely separated localities would indicate that rust reaction was fairly constant

when the same strains of oats were grown in different places in Minnesota. The correlation of + .16 ± .11 between lodging at University Farm and Waseca indicated that lodging in these two localities was due to different factors.

In Table 7 are given the total correlations between yield at University Farm and Waseca and of plumpness at the same places, as well as the partial correlation coefficients when date heading, crown rust, or lodging at both places were held constant.

TABLE 7.—*Total and partial correlation coefficients of yield or plumpness of 38 strains of oats grown at University Farm and Waseca in 1927.*

Characters correlated: Yield		Plumpness	
r_{YuYw}*	= +.61±.07	r_{PuPw}	= +.71±.06
$r_{YuYw.DuDw}$	= +.68±.06	$r_{PuPw.DuDw}$	= +.70±.06
$r_{YuYw.RuRw}$	= +.73±.05	$r_{PuPw.RuRw}$	= +.74±.05
$r_{YuYw.LuLw}$	= +.67±.06	$r_{PuPw.LuLw}$	= +.74±.05
$r_{YuYw.DuDwRuRwLuLw}$	= +.62±.08	$r_{PuPw.DuDwRuRwLuLw}$	= +.60±.07

*Where Y_u = yield at University Farm, Y_w = yield at Waseca, D_u = date heading at University Farm, etc.

With crown rust held constant the correlation coefficient between yield at University Farm and Waseca was increased from + .61 ± .07 to + .73 ± .05. The difference between these two correlation coefficients is not statistically significant. In general, it could be said that neither date heading, crown rust, nor lodging had a materially different effect on yield or plumpness of the same oat strains when grown at University Farm or at Waseca.

SUMMARY

1. A biometrical study was made of the characters associated with yield in rod rows of oats grown at University Farm, St. Paul, and at the Waseca, Crookston, and Morris branch experiment stations in 1927.

2. Plumpness of grain, date heading, crown rust, and lodging were closely associated with yield. Height of plants and blast or spikelet blight had very little influence on yield.

3. The true relationship between yield and crown rust or yield and date heading was masked in the total correlation coefficients and could only be determined when a partial correlation study was made.

4. Yields of the same strains of oats grown at University Farm, Waseca, and Crookston were highly correlated. These same strains did not respond in the same uniform manner at Morris as at University Farm or Crookston, as determined from the correlation coefficient.

5. A multiple correlation coefficient of .82 ± .01 was obtained when yield was correlated with the factors plumpness, date heading, height, crown rust, and lodging of 280 strains of oats grown at University Farm. This would mean that 67% of the total squared variability in yield could be explained in terms of its mathematical relations to the five variables considered.

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ERADICATING QUACK GRASS WITH SODIUM CHLORATE[1]

ALBERT A. HANSEN[2]

Throughout the area eastward from the Dakotas and Nebraska quack grass is not only considered as the worst of field weeds but the nuisance is steadily enlarging its range. Once established, the land is of little value except for pasture since no reliable method of eradication over large infested areas exists.

Quack grass usually starts in the form of one or more small patches after being introduced by means of impure seed. The average farmer pays little attention to the newcomer, which to all appearances is an ordinary harmless grass, until new patches arise in all parts of the field as a result of root pieces distributed by cultivating implements. To date, the only reliable method of destroying such patches before they spread into a solid infestation is covering with tin roofing, tar paper, or any other material that completely excludes the light for a period of three months. It will be seen at once that this method has serious disadvantages aside from the expense involved, and it is impractical where livestock has access to the infested area.

The need for a quicker and cheaper method has long been felt. The writer has tried a number of chemical weed killers with indifferent results until sodium chlorate was used during the season of 1926 against a solid area of the grass 2 rods in length and about 4 feet wide, growing along a fence row at West Lafayette, Indiana. Sodium chlorate has been found to be effective against Canada thistle by Aslander[3] and against field bindweed by Latshaw and Zahnley,[4] but no data were available regarding its value against quack grass and other weeds.

The material was dissolved in water at the rate of 1 pound per gallon, and applied with a sprinkling can during late June when the heads were reaching maturity. The treated plants soon turned light brown and within a week the tops were apparently dead. A number of the roots were dug up and they were found to be brown

[1]Contribution from the Department of Botany, Purdue University Agricultural Experiment Station, Lafayette, Ind. Received for publication August 6, 1928.

[2]Associate Botanist.

[3]ASLANDER, ALFRED. Chlorates as plant poisons. Jour. Amer. Soc. Agron., 18: 1101–1102. 1926.

[4]LATSHAW, W. L., and ZAHNLEY, J. W. Experiments with sodium chlorate and other chemicals as herbicides for field bindweed. Jour. Agr. Res., 35: 757–767. 1927.

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and lifeless. The patch was closely watched during the remainder of the season and throughout the summer of 1927, but no evidence of sprouting could be found.

Also, during June, 1927, two small patches of quack grass each 5 feet square were mowed and one was saturated with sodium chlorate prepared at the rate of 0.5 pound per gallon and the other at the rate of 1 pound per gallon. A month later sprouting was observed where the weaker solution was applied, but no evidence of quack grass has since been found on the plat where the pound per gallon solution was used. It is interesting to note that within a month crab grass, orchard grass, and other vegetation appeared on the treated area, indicating that the chlorate does not injure the soil.

Encouraged by these preliminary tests, a series of six plats each 10 feet square were staked out along the right of way of the Monon Railroad near Taylor Station, Indiana, on a solid area of quack grass. During the previous season this area had been saturated with a solution of concentrated sodium arsenite of the grade known as 4-pound material, containing about 32% arsenous oxide (As_2O_3) soluble in water. This was used at the rate of 1 part in 20 and applied at the rate of 400 gallons per acre. The arsenic proved to be a complete failure since the quack grass developed very thickly the following spring.

The six plats were mowed on August 30 and treated as follows on September 30:

Plat 1.—Sprinkled with a 5% (0.5 pound per gallon) solution of sodium chlorate.

Plat 2.—Sprinkled with a 10% (1 pound per gallon) solution of sodium chlorate. The sprouts on a typical square foot were first counted and found to number 147.

Plat 3.—Check.

Plat 4.—Sprinkled with a 20% (2 pounds per gallon) solution of sodium chlorate.

Plat 5.—Check.

Plat 6.—Dry sodium chlorate was scattered evenly over the 100 square feet. This plat contained 72 sprouts per square foot.

In each case the material was applied with an ordinary sprinkling can at the rate of 10 gallons per 100 square feet. The weather was clear on the day of application but heavy rains fell about 10 hours later.

The plats were examined on October 2 and all the vegetation on the treated area was apparently dead, the brown appearance being in marked contrast to the surrounding green and the check plats. On

October 13 there was some evidence of greening in a few of the old tops on plat 1, but no sprouts could be found.

On November 15 four sprouts were found on plat 1, two on plat 2, two on plat 4, and ten on plat 6. The sprouts seemed to originate from thickened joints where there was an accumulation of reserve food.

An examination on May 1 of the following spring revealed no evidence of sprouting except on plat 6. On June 21, 41 sprouts were found on plat 1, no sprouts on plats 2 or 4, while plat 6 showed about 5% recovery. No evidence of live roots could be found after careful examination on plats 2 or 4.

These tests indicate that patches of quack grass can be eradicated by mowing and saturating a month later with sodium chlorate used at the rate of 1 pound per gallon. Several additional trials substantiate this viewpoint. On May 15, 1928, a solid patch of about 10 square yards on the Purdue campus was treated with sodium chlorate solution prepared at the rate of 1 pound per gallon and two months later the ground was bare of quack grass and ready for reseeding, some clover having worked its way in. Digging into the soil showed no evidence of live roots. Cooperative tests with a number of farmers in Indiana indicate that patches of quack grass can be destroyed with one or two sprayings or sprinklings of a 10% solution of sodium chlorate, providing the tops are completely saturated. Best results are secured when the grass is mowed and the sprouts saturated when they are from 6 to 10 inches high. Under farm conditions at least two applications are usually necessary to secure complete eradication and sometimes more where the work has not been carefully done.

In addition to being far more effective than sodium arsenite, the standard commercial herbicide, sodium chlorate has the important advantage of not being poisonous to man, farm animals, or the soil. It is not so expensive as to be impractical since it can be secured in 112-pound steel kegs for 6½ cents per pound f.o.b. Niagara Falls, New York. It can be most economically applied with a sprayer of any type but care must be exercised to clean the sprayer thoroughly after use. The material is said to be inflammable when in contact with organic matter and it should not be mixed indoors, although no trouble of this character has been experienced in Indiana where we have definite record of over a hundred farmers who have used sodium chlorate for weed-killing purposes.

The exact manner in which sodium chlorate acts on plants is not known. A microscopic examination of treated plants indicates that the material penetrates through the phloem tissue. It has been

suggested that the chemical interferes with photosynthetic activity, but this is very doubtful since in tests with poison ivy the material was applied after the leaves had been killed by frost.

Sodium chlorate is a white crystalline substance somewhat resembling common salt, although it is not salty to the taste.

AGRONOMIC AFFAIRS

ANNUAL MEETING OF THE SOCIETY

The Annual Meeting of the Society will be held in the New Willard Hotel, Washington, D. C., November 22 and 23. The program as outlined by President McCall follows:

THURSDAY, NOVEMBER 22

8:30 A. M.
Social Hour

9:30 A. M.

Meeting called to order by President McCall.
Appointment of committees.
Symposium on "Soil Organic Matter and Green Manuring."
Leader: J. G. Lipman, New Jersey Experiment Station.

2:00 P. M.

Symposium on "Application of Base Exchange Methods."
Leader: F. W. Parker, Alabama Experiment Station.
Extension Sectional Program.
Leader: O. S. Fisher, U. S. Dept. of Agriculture.

6:30 P. M.

Banquet
President's address
Business meeting
Committee reports (brief)
Election of officers
New business
Announcements

FRIDAY, NOVEMBER 23

8:30 A. M.

SOILS SECTIONAL PROGRAM

Symposium on "Soil Erosion."
Leader: H. H. Bennett, U. S. Dept. of Agriculture.

CROPS SECTIONAL PROGRAM

Symposium on "Tobacco Research."
Leader: W. L. Slate, Connecticut Experiment Station.

2:00 P. M.

Open sessions for contributed papers on both soils and crops.

NEWS ITEMS

DR. SANTE MATTSON, formerly of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, became a member of the research staff of the New Jersey Agricultural Experiment Station on July 1. Dr. Mattson will devote his time to studies of colloids, base exchange, and physical properties of soils.

DR. SELMAN A. WAKSMAN, microbiologist of the New Jersey Experiment Station, accompanied by Dr. A. P. Dachnowski-Stokes of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, visited a number of peat bogs of the highmoor type in Maine during August for the purpose of studying chemical composition and bacteriological activities of the various profiles.

DR. H. C. MCLEAN, soil bacteriologist of the New Jersey Experiment Station, has been released from his duties in the Department of Chemistry and Microbiology to study the subject of arsenical spray residues on fruit.

MRS. ANASTASIA ROKITZKAIA of the Soil Amelioration Institute, Leningrad, Russia, has returned to this country to resume her studies in soil microbiology at Rutgers University.

S. M. RAVIKOVITCH of the Experiment Station at Tel-Aviv, Palestine, has taken up graduate studies in soil chemistry at Rutgers University.

DR. JACOB S. JOFFE, research assistant in soils, New Jersey Experiment Station, left on June 15 for a four month tour of Europe. Dr. Joffe will make some studies in methods of conducting lysimeter work in England, France, Germany, and Russia.

ALLAN V. KING has resigned from the Synthetic Nitrogen Products fellowship to become Assistant in Chemistry in Rutgers University.

ERNEST SPENCER, a graduate of Massachusetts Agricultural College, has accepted the William P Jenks fellowship at Rutgers University. His problem will be the influence of soil reaction on Ericatious plants.

AT THE July Convocation of Degrees of the University of Wales, the degree of Doctor in Scientia was conferred upon Professor Walter Thomas of the Pennsylvania Agricultural Experiment Station.

BURTON B. BAYLES, Assistant Agronomist of the office of Cereal Crops and Diseases, U. S. Bureau of Plant Industry, in charge of cooperative cereal investigations at the Judith Basin Substation, Moccasin, Montana, has been granted leave without pay for the school year beginning October 1, 1928, to engage in graduate study at the University of Wisconsin. He is especially interested in the problem of winterhardiness in wheats.

J. H. SHOLLENBERGER, in charge of the milling investigations laboratory of the Grain Division of the Bureau of Agricultural Economics, U. S. Dept. of Agriculture, resigned in September to take charge of his father's flour mill in Pennsylvania.

H. R. SUMNER, Extension Farm Crop Specialist of the Kansas Agricultural College, was appointed Director of the Spring Wheat Improvement Association, formed by a group of Minneapolis business men and commercial organizations, and took up his new headquarters at Minneapolis in July.

O. MCCONKEY of the Field Husbandry Department of the Ontario Agricultural College, Guelph, Canada, has been granted leave for study and research in England and will visit several of the European experiment stations before returning to Canada.

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THE DRIFT IN POTENTIAL OF THE QUINHYDRONE ELECTRODE[1]

L. D. BAVER[2]

In the use of the quinhydrone electrode, which is being employed rather extensively for measuring the H-ion concentration of soils, different investigators report varied success. Most of the adverse criticism regarding its value for determining the reaction of soils is based on the drift in potential that occurs with practically all soils. This gradual change in the measured pH value of a soil, according to some investigators, is of such a nature as to make the use of the quinhydrone electrode somewhat questionable. On the other hand, other workers claim that this change is insignificant in soil investigations and that the quinhydrone method is to be recommended for measuring the soil reaction.

Biilmann (3,4,5),[3] in discussing the drift in potential of the quinhydrone electrode, attributes these changes to deviations in the value of the ratio between the molecular concentrations of quinone and hydroquinone. The quotient of these concentrations, log $\frac{\text{conc. of quinone}}{\text{conc. of hydroquinone}}$, is normally unity. Any reaction between the quinhydrone and the examined substances that tends to change this ratio from unity will cause a drift in potential. However, since this ratio is logarithmic, Biilmann concludes that "for values of 0.10 in pH, which is close enough for soil work, the value of this fraction can deviate considerably from unity."

Variations in the pH value of a soil may then be due to several factors which may influence the quinhydrone. The soil may contain

[1]Contribution from the Departent of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication August 1, 1928.

[2]Assistant in Agronomy (Soil Physics).

[3]Reference by number is to "Literature Cited," p. 1139.

oxidizing or reducing substances. The hydroquinone may be oxidized or the quinone reduced. The soil may have a selective adsorptive power for the components of the quinhydrone. In either case, the ratio of their molecular concentrations will be changed causing deviations in the potential. In alkaline solutions, the hydroquinone may act as a weak acid neutralizing some of the bases and producing changes in the pH values.

Biilmann and Jensen (6) state that if the soil has chemical or adsorbing effects on the components of the quinhydrone, they are either instantaneous, producing no drift in potential, or they are gradual, causing small changes in the pH values with time. Therefore, readings taken immediately after placing the electrodes into the soil suspension would be more nearly correct. They say further,

> "In the reaction in the soil-water mixture, the reaction of that part of the suspension which is in contact with the platinum electrode is measured. Equilibrium is attained more rapidly the larger the soil surface that is presented in proportion to the amount of water used. It is only necessary to attain equilibrium between the soil and water in that part of the suspension which is in contact with the platinum foil; in a very thin film of the mixture through which diffusion from those parts of the liquid in direct contact with the soil particles to the parts of the liquid in immediate contact with the platinum foil happens very quickly. After shaking the soil-water mixture for a few seconds and measuring immediately with an electrode entirely submerged in the soil and water mixture, we measure a reaction corresponding to the equilibrium between the soil and water."

They also stress the importance of the cleanliness of the metallic electrodes. A drift in potential was always experienced with unclean electrodes.

In a former publication the author (2) reports that equilibrium with the quinhydrone electrode was quickly attained. Kappen and Beling (11) report that the end potential is obtained in a very short time. Hetterschij and Hudig (8) recommend that readings should be taken immediately. Arnd and Siemers (1) conclude that the pH values should be observed after the electrode has been in the suspension for five minutes. Snyder (14) reports that equilibrium appears to be reached from 5 to 10 minutes. Von'Sigmond (15) proposes first to mix the soil with water and after a few minutes add the quinhydrone and make the readings.

Hissink and van der Spek (10) claim that the deviations in pH readings are not due to the decomposition of quinhydrone, especially in acid soils, but to the fact that equilibrium has not been established. Hissink (9) states that readings taken immediately after shaking do

not give true results. He favors peptizing the soil with water for 18 to 20 hours and waiting for 30 minutes before observing the pH values. Novak (12) also maintains that the measurement of potential should not begin immediately after dipping the electrodes into the soil suspension since it has not come to equilibrium.

It is the purpose of this paper to show the effects of different factors upon changes in the measured pH values of various soils. The pH readings, taken at different time intervals, are compared with the results obtained with the hydrogen electrode. The hydrogen electrode values were obtained when the electrode had reached equilibrium. This time varied from 15 to 30 minutes.

EXPERIMENTAL

RELATION OF DIFFERENT COMPARISON ELECTRODES TO pH VALUES OF VARIOUS SOILS

Different investigators appear to favor different comparison cells with the use of the quinhydrone electrode. There are two distinct types of cells which may be used. There is the possibility of using a calomel electrode as the comparison cell which has the advantage that once it is made its potential remains constant over a long period of time. Also, there are those types of reference electrodes whose potential is constant for a relatively short time. The potassium acid phthalate cell and the cell whose electrolyte consists of a solution of 0.01N HCl and 0.09N KCl belong to this class. The latter electrode is used rather extensively by European investigators. This type of cell has the advantage in that it is easily made.

Three different comparison cells were used in this study, the saturated calomel, N/20 potassium acid phthalate, and the 0.01N HCl plus 0.09N KCl electrodes. With the saturated calomel cell, the equation for calculating the pH of a given solution at 25° C is

$$pH = \frac{0.4526 - \pi}{0.0591} \qquad (1)$$

The correction for temperature deviations from 25° C were made according to the chart given by Clark and Collins (7).

The equation to be used with the N/20 potassium acid phthalate cell at 25° is

$$pH = 3.97 + \frac{\pi}{0.0591} \qquad (2)$$

The equation for the 0.01 N HCl and 0.09N KCl cell at 25° C is

$$pH = 2.10 + \frac{\pi}{0.0591} \qquad (3)$$

Temperature corrections were made according to the tables given by Biilmann (3).

The phthalate and the HCl-KCl mixture were placed in test tubes and mixed with the quinhydrone. A bright platinum foil served as the metallic electrode in these two cells. Contact with the soil suspension was made by means of a saturated KCl-agar bridge. The metallic electrode used in the soil suspension was a bright platinum cone made from platinum wire as described by Sideris (13). Twenty grams of soil and 20 cc of distilled water were mixed with about 0.10 gram of quinhydrone in a 100-cc beaker. The platinum cone, the three agar bridges from the comparison cells, and the mechanical stirrer were immersed in the soil suspension. Readings were taken at different time intervals for one hour. The suspension was stirred continuously during this time. Except where otherwise stated, this method of stirring was used throughout these investigations. The three reference electrodes were connected with the potentiometer through mercury cups which facilitated changing from one electrode to another. Readings were made with a Leeds and Northrup potentiometer and sensitive galvanometer. The pH values are calculated to read to the third decimal place in order to show the fluctations in the pH values with time. Reading to the first decimal place is sufficient for practical purposes.

The results given in Table 1 show that the values obtained with the three electrodes agree fairly well. The change in pH, which is designated as Δ pH, is the largest change in pH occurring during the 60 minutes and does not mean the change in pH as observed between the first and last readings. For example, using the phthalate electrode with Soil 145 there is an increase of 0.164 in pH during 10 minutes. The pH value then decreases gradually, a decrease of 0.045 in pH from 10 to 60 minutes. The Δ pH of + 0.164 is obtained from the difference in pH as measured instantly and at 10 minutes. In other words, the largest deviation in pH occurred during the first 10 minutes. The deviations in the pH values vary with the three electrodes with the different soils. However, since the calomel electrode is the most stable, it is preferred and all the following experiments were carried out using a saturated calomel cell.

TABLE 1.—*The relation of different comparison electrodes to the pH values of various soils.*

Soil No.	Comparison electrode	pH values at different time intervals in minutes Instantly	1	2	3	4	5	10	15	20	30	40	50	60	Δ pH
	Calomel	3.932	3.932	3.923	3.915	3.898	3.898	3.863	3.852	3.842	3.822	3.805	3.780	3.762	—0.170
105	Phthalate	3.960	3.925	3.917	3.908	3.891	3.885	3.848	3.836	3.824	3.802	3.770	3.749	3.742	—0.218
H = pH 4.05	HCl-KCl	3.894	3.874	3.866	3.856	3.851	3.848	3.834	3.822	3.804	3.787	3.765	3.754	3.741	—0.153
	Calomel	5.050	5.028	5.015	4.998	4.998	4.987	4.975	4.940	4.913	4.863	4.830	4.803	4.797	—0.253
150	Phthalate	5.137	5.111	5.094	5.086	5.076	5.068	5.024	4.990	4.974	4.903	4.869	4.843	4.817	—0.320
H = pH 5.14	HCl-KCl	5.086	5.043	5.026	5.009	4.999	4.994	4.991	4.974	4.974	4.922	4.895	4.870	4.853	—0.233
	Calomel	6.013	6.055	6.115	6.090	6.115	6.142	6.150	6.175	6.183	6.192	6.192	6.175	6.167	+0.179
145	Phthalate	6.135	6.187	6.211	6.229	6.237	6.254	6.229	6.289	6.281	6.281	6.281	6.263	6.254	+0.164
H = pH 6.07	HCl-KCl	6.100	6.160	6.212	6.222	6.238	6.266	6.278	6.298	6.298	6.298	6.298	6.298	6.290	+0.198
	Calomel	6.615	6.692	6.742	6.792	6.860	6.885	6.735	6.835	6.868	6.893	6.898	6.898	6.898	+0.283
178	Phthalate	6.887	6.947	6.964	6.981	6.981	6.973	6.904	6.921	6.904	6.904	6.780	6.770	6.770	—0.211
H = pH 6.40	HCl-KCl	6.333	6.481	6.550	6.583	6.610	6.654	6.800	6.862	6.882	6.882	6.862	6.852	6.844	+0.549
	Calomel	8.238	8.242	8.238	8.222	8.203	8.188	8.153	8.053	8.037	7.998	7.985	7.942	7.900	—0.342
204	Phthalate	8.289	8.341	8.326	8.326	8.280	8.272	8.255	8.203	8.151	8.055	7.986	7.943	7.891	—0.450
H = pH 8.11	HCl-KCl	8.230	8.282	8.272	8.267	8.238	8.225	8.208	8.143	8.099	8.022	7.961	7.908	7.876	—0.406

TABLE 2.—*The relation of different metallic electrodes to changes in the pH of soils when measured by the quinhydrone electrode.*

Soil No.	Metallic electrode	pH values at different time intervals in minutes													
		Instantly	1	2	3	4	5	10	15	20	30	40	50	60	Δ pH
	Platinum cone	3.910	3.910	3.892	3.892	3.892	3.902	3.907	3.913	3.923	3.928	3.935	3.938	3.928	+0.046
105	Platinum foil	3.867	3.875	3.883	3.892	3.892	3.902	3.910	3.918	3.927	3.935	3.938	3.938	3.928	+0.071
H = pH 4.05	Platinum gauze	3.892	3.892	3.892	3.895	3.902	3.907	3.919	3.918	3.927	3.935	3.935	3.935	3.928	+0.043
	Gold foil	3.867	3.875	3.883	3.892	3.892	3.902	3.910	3.918	3.927	3.935	3.938	3.938	3.928	+0.071
	Platinum cone	5.077	5.085	5.077	5.082	5.078	5.078	5.077	5.078	5.082	5.082	5.078	5.077	5.068	—0.017
150	Platinum foil	5.090	5.090	5.085	5.085	5.085	5.082	5.082	5.082	5.082	5.082	5.080	5.073	5.068	—0.022
H = pH 5.14	Platinum gauze	5.085	5.073	5.082	5.082	5.082	5.078	5.078	5.078	5.082	5.082	5.080	5.073	5.068	—0.017
	Gold foil	5.105	5.098	5.098	5.098	5.095	5.090	5.082	5.085	5.085	5.085	5.082	5.078	5.073	—0.032
	Platinum cone	5.960	5.970	6.020	6.038	6.062	6.078	6.095	6.182	6.198	6.232	6.248	6.262	6.275	+0.315
145	Platinum foil	5.943	6.023	6.037	6.048	6.062	6.087	6.112	6.182	6.198	6.232	6.248	6.262	6.275	+0.332
H = pH 6.07	Platinum gauze	5.943	6.012	6.032	6.053	6.070	6.087	6.122	6.182	6.207	6.232	6.252	6.265	6.280	+0.337
	Gold foil	5.960	5.970	6.028	6.048	6.062	6.078	6.095	6.182	6.198	6.232	6.248	6.262	6.275	+0.315
	Platinum cone	6.563	6.623	6.648	6.673	6.690	6.698	6.750	6.797	6.808	6.825	6.808	6.842	6.858	+0.295
178	Platinum foil	6.555	6.623	6.648	6.667	6.682	6.698	6.750	6.792	6.808	6.820	6.808	6.850	6.858	+0.303
H = pH 6.40	Platinum gauze	6.598	6.632	6.667	6.667	6.698	6.708	6.750	6.792	6.817	6.825	6.808	6.850	6.858	+0.260
	Gold foil	6.572	6.615	6.648	6.667	6.690	6.698	6.747	6.797	6.808	6.825	6.808	6.850	6.858	+0.286
	Platinum cone	8.138	8.213	8.222	8.233	8.238	8.243	8.248	8.230	8.210	8.187	8.155	8.122	8.088	—0.160
204	Platinum foil	8.188	8.213	8.230	8.233	8.238	8.248	8.248	8.230	8.210	8.187	8.155	8.122	8.088	—0.160
H = pH 8.11	Platinum gauze	8.197	8.213	8.230	8.233	8.238	8.248	8.248	8.230	8.210	8.187	8.155	8.122	8.088	—0.160
	Gold foil	8.180	8.213	8.230	8.233	8.238	8.248	8.248	8.230	8.210	8.187	8.155	8.122	8.088	—0.160

RELATION OF DIFFERENT METALLIC ELECTRODES TO CHANGES IN pH

In order to determine if the metallic electrode influenced the drift in potential with the quinhydrone method, four different electrodes were immersed in the soil suspension. Platinum cone, platinum foil, platinum gauze, and gold foil electrodes were used. They were cleaned with a hot chromic acid mixture, rinsed with distilled water, and heated to redness in an alcohol flame. Contact with the potentiometer was made through mercury cups so that the readings with the different electrodes could be made as nearly simultaneously as possible.

The results in Table 2 show no significant differences between the pH values obtained with the different electrodes. The change in pH during 60 minutes was practically the same. Biilmann states that gold or gold-plated electrodes are less sensitive to disturbing influences in the solution. However, he favors a bright platinum electrode for most reaction work. Snyder (14) reports that gold electrodes are preferable to platinum. However, in measuring the reaction of soils, the bright platinum cone has the distinct advantage of being more rigid and compact, occupying a small space in the soil suspensions and at the same time exposing a large surface area. It was used in these investigations except where otherwise stated.

EFFECT OF STIRRING UPON CONSTANCY OF pH READINGS

A mixture that is homogeneous should give more constant pH readings than one in which there may be differences in the reaction throughout the suspension. In the latter case, the electrode may be immersed in two or more parts of the suspension having different reactions which would tend to give fluctuating readings. Therefore, if the soil suspension is stirred, more exact values might be expected. In this experiment a bright gold foil and a bright platinum cone electrode were placed in the soil suspension. Readings were taken while the suspension was allowed to settle. The suspension was then stirred for 0.5 minute and readings taken again. The results of these observations are given in Table 3 and Fig 1. The column marked "unstirred" refers to the soil suspension at rest and "stirred" to the suspension after it had been mechanically stirred for 0.5 minute. With the exception of Soil 150, in which there was little difference between the values obtained by the two methods, stirring has reduced the fluctuations in the pH values. Therefore, it appears that mechanical stirring is advantageous in pH determinations with the quinhydrone electrode.

TABLE 3.—*The effect of stirring upon the constancy of pH readings with the quinhydrone electrode.*

Soil No.	Electrode		pH values at different time intervals in minutes									
			1	5	10	15	20	30	40	50	60	Δ pH
	Platinum	Stirred*	3.975	3.983	3.988	3.983	3.983	3.983	3.975	3.975	3.963	—0.025
105		Unstirred†	4.037	4.055	4.108	4.100	4.092	4.117	4.105	4.095	4.100	+0.080
	Gold	Stirred	3.983	3.988	3.988	3.983	3.983	3.983	3.975	3.975	3.963	—0.025
H = pH 4.05		Unstirred	4.042	4.062	4.112	4.108	4.095	4.122	4.108	4.100	4.100	+0.080
	Platinum	Stirred	5.100	5.088	5.088	5.088	5.078	5.078	5.072	5.062	5.058	—0.042
150		Unstirred	5.117	5.095	5.105	5.108	5.100	5.122	5.108	5.105	5.092	—0.030
	Gold	Stirred	5.125	5.088	5.088	5.088	5.078	5.078	5.072	5.062	5.058	—0.067
H = pH 5.14		Unstirred	5.117	5.100	5.105	5.117	5.100	5.122	5.108	5.105	5.092	—0.030
	Platinum	Stirred	6.022	6.087	6.120	6.155	6.172	6.205	6.222	6.225	6.240	+0.218
145		Unstirred	6.035	6.072	6.115	6.188	6.208	6.230	6.243	6.275	6.292	+0.257
	Gold	Stirred	6.022	6.088	6.120	6.155	6.172	6.205	6.222	6.225	6.240	+0.218
H = pH 6.07		Unstirred	6.035	6.082	6.120	6.192	6.208	6.222	6.243	6.278	6.285	+0.250
	Platinum	Stirred	6.582	6.708	6.782	6.800	6.843	6.865	6.860	6.848	6.835	+0.283
178		Unstirred	6.565	6.860	6.872	6.915	6.918	6.927	6.935	6.927	6.918	+0.370
	Gold	Stirred	6.582	6.717	6.782	6.808	6.848	6.865	6.860	6.848	6.835	+0.283
H = pH 6.40		Unstirred	6.598	6.868	6.888	6.915	6.925	6.927	6.943	6.935	6.927	+0.345
	Platinum	Stirred	8.112	8.193	8.189	8.175	8.170	8.150	8.128	8.107	8.087	—0.106
204		Unstirred	8.037	8.189	8.241	8.238	8.221	8.213	8.193	8.170	8.145	+0.104
	Gold	Stirred	8.153	8.193	8.189	8.178	8.170	8.145	8.128	8.103	8.090	—0.099
H = pH 8.11		Unstirred	8.189	8.238	8.235	8.225	8.208	8.193	8.175	8.153	8.128	—0.107

*Stirred for 0.5 minute while readings were made.

†Suspension allowed to settle except during the 0.5-minute periods of stirring.

TABLE 4.—*The effect of placing the platinum electrode in different parts of the soil suspension on pH readings.*

Soil No.	Part of the suspension holding electrode	pH values at different time intervals in minutes: 1	5	10	15	20	30	40	50	60	Shaken at 60	Δ pH
105	Upper	4.108	4.160	4.177	4.190	4.193	4.193	4.190	4.187	4.177	4.091	+0.085
H=pH 4.05	Lower	4.108	4.143	4.152	4.160	4.160	4.157	4.147	4.117	4.108	4.091	+0.052
	Stirred*	3.975	3.983	3.988	3.983	3.983	3.983	3.975	3.975	3.963	——	—0.025
150	Upper	5.158	5.202	5.213	5.227	5.230	5.240	5.243	5.252	5.252	5.105	+0.094
H=pH 5.14	Lower	5.133	5.128	5.133	5.133	5.128	5.125	5.122	5.112	5.112	5.105	—0.011
	Stirred	5.100	5.088	5.088	5.088	5.078	5.078	5.072	5.062	5.058	——	—0.042
145	Upper	6.192	6.105	6.123	6.200	6.167	6.145	6.120	6.137	6.123	6.138	+0.095
H=pH 6.07	Lower	6.105	5.958	5.952	6.082	6.063	6.042	6.022	6.005	5.978	6.123	—0 153
	Stirred	6.022	6.087	6.120	6.155	6.172	6.205	6.222	6.225	6.240	——	+0.218
178	Upper	6.635	6.882	6.882	6.877	6.872	6.852	6.832	6.808	6.792	6.750	+0.247
H=pH 6.40	Lower	6.582	6.632	6.635	6.635	6.635	6.635	6.632	6.632	6.675	6.742	+0.093
	Stirred	6.582	6.708	6.782	6.800	6.843	6.865	6.860	6.848	6.835	——	+0.283
204	Upper	8.238	8.263	8.230	8.202	8.170	8.128	8.095	8.063	8.028	8.173	—0.235
H=pH 8.11	Lower	8.222	8.258	8.222	8.188	8.140	8.078	8.033	7.988	7.953	8.173	—0.305
	Stirred	8.112	8.193	8.189	8.175	8.170	8.150	8.128	8.107	8.089	——	—0.106

*Results taken from Table 3, Column 1.

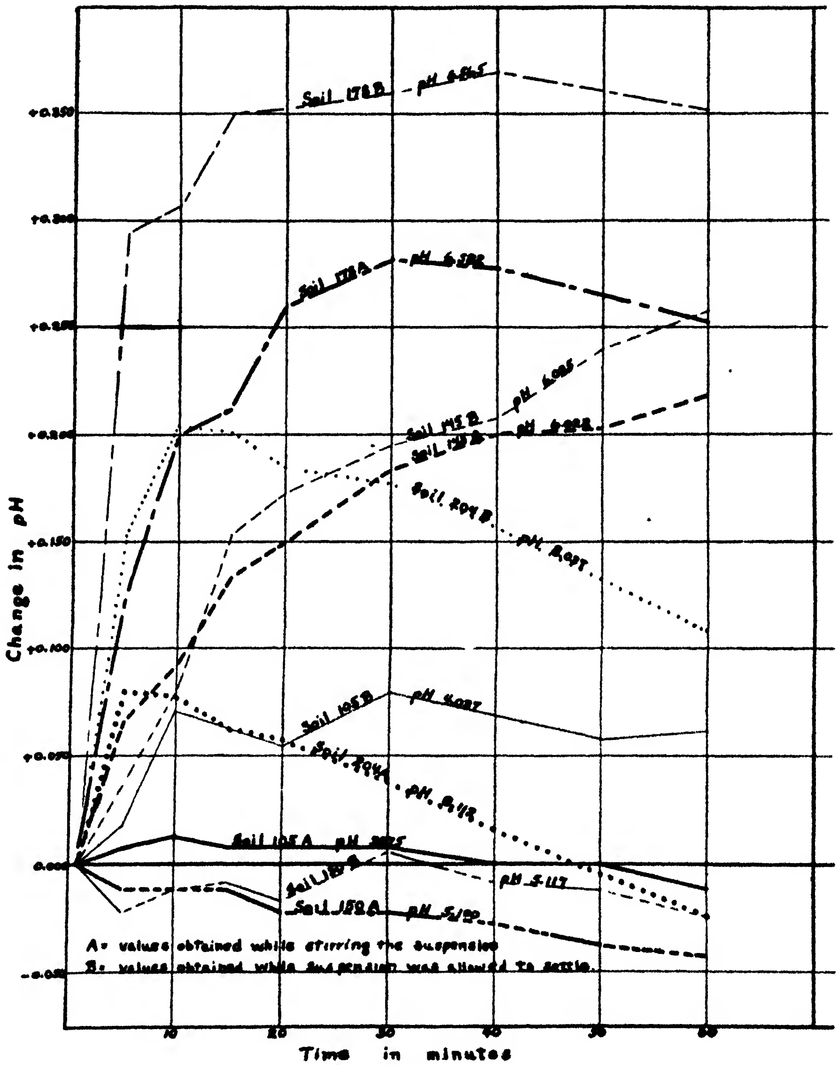

Fig. 2

In order to find out the differences that may exist in different parts of the soil suspension, 15 grams of soil and 15 cc of water were thoroughly shaken with quinhydrone in a large test tube. Two bright platinum foil electrodes were placed in this suspension. One was placed in the lower part of the suspension where the soil particles settled out. The other was placed in the upper part where only the finer particles remained in suspension. Table 4 shows the variation in the pH values with time in both parts of the suspension. The

lower part of the suspension is slightly more acid or less alkaline than the upper. Clark and Collins (7) report the opposite to be true. The fluctuations in pH tend to be a little greater in the upper part of the suspension. The pH values of the suspensions when they were shaken after 60 minutes are slightly less than the original readings with the exception of Soil 178. Shaking and stirring the suspension give values that are more comparable with the hydrogen electrode values. In Tables 1,2,3, and 4 the hydrogen electrode readings are given under the soil number.

USE OF RECRYSTALLIZED QUINHYDRONE

Arnd and Siemers (1) report that they obtained better results with the quinhydrone electrode when they used quinhydrone that was recrystallized. A c.p. commercial quinhydrone, obtained from the Eastman Kodak Company, was recrystallized in warm water at 70° C, filtered, and allowed to dry at room temperatures for two days. The results in Table 5 show that the fluctuations in the pH values with the recrystallized quinhydrone are about the same as those obtained with the c.p. commercial product. The c.p. commercial product was used in all the other determinations.

TABLE 5.—*The use of recrystallized quinhydrone and its effect upon the changes in pH.*

Soil No.	pH values at different time intervals in minutes									
	1	5	10	15	20	30	40	50	60	Δ pH
105	3.950	3.982	3.982	3.982	3.973	3.973	3.967	3.962	3.957	+0.032
150	5.088	5.073	5.073	5.068	5.065	5.052	5.038	5.030	5.017	—0.071
145	6.008	6.092	6.157	6.195	6.220	6.255	6.272	6.280	6.288	+0.280
178	6.552	6.700	6.757	6.790	6.795	6.803	6.812	6.817	6.817	+0.265
204	8.168	8.180	8.192	8.168	8.133	8.080	7.993	7.980	7.938	—0.254

EFFECT OF PASSING CO_2-FREE AIR AND HYDROGEN THROUGH SOIL SUSPENSION

Arnd and Siemers (1) state that they had varied success with the quinhydrone method by passing either CO_2-free air or hydrogen through the soil suspension, claiming that the CO_2 was removed from the suspension which reduced the amount of creep in the pH readings. In this experiment, CO_2-free air was passed through all the soil suspensions while readings were being made. Hydrogen was passed through the soil suspension with Soils 145 and 178, the two soils that exhibited the largest fluctuations in pH during one hour. No significant effects on the change in pH were observed, either with the use of CO -free air or hydrogen. The results are shown in Table 6.

TABLE 6.—*The effect of passing CO_2-free air and hydrogen through the soil suspension upon the pH readings.*

Soil No.		pH values at different time intervals in minutes 1	5	10	15	20	30	40	50	60	Δ pH
105	Air	3.957	3.978	3.975	3.987	3.992	3.978	4.012	3.960	3.960	+0.035
150	Air	5.125	5.143	5.125	5.117	5.108	5.108	5.058	5.058	5.042	—0.101
145	Air	5.997	6.042	6.125	6.163	6.192	6.235	6.235	6.243	6.252	+0.255
	H	5.963	5.988	6.107	6.130	6.132	6.158	6.172	6.172	6.180	+0.117
178	Air	6.657	6.817	6.842	6.898	6.868	6.893	6.848	6.838	6.838	+0.236
	H	6.463	6.675	6.688	6.735	6.752	6.785	6.798	6.815	6.827	+0.364
240	Air	8.128	8.157	8.128	8.112	8.078	8.037	7.985	7.963	7.917	—0.240

EFFECT OF PREVIOUS PEPTIZATION OF SOIL WITH WATER

Hissink and van der Spek (10) recommend that the soil should be peptized with water for 20 hours before determining the reaction with the quinhydrone electrode. The establishment of equilibrium is thereby hastened. In this study, the soil was thoroughly mixed with water and the suspension allowed to stand over night. Quinhydrone was added immediately before making the pH readings. The data given in Table 7 show that this preliminary treatment has not affected the deviation in the pH values of these soils. Evidently, the drift in potential is not due to the fact that equilibrium has not been attained but to some disturbing influence on the quinhydrone.

TABLE 7.—*pH values of soil suspensions allowed to stand over night.*

Soil No.	pH values at different time intervals in minutes 1	5	10	15	20	30	40	50	60	Δ pH
105	3.940	3.957	3.960	3.960	3.960	3.960	3.957	3.953	3.953	+0.020
150	5.142	5.133	5.126	5.117	5.105	5.088	5.075	5.058	5.042	—0.100
145	6.100	6.193	6.267	6.300	6.333	6.377	6.407	6.407	6.407	+0.307
178	6.425	6.662	6.745	6.770	6.790	6.802	6.830	6.813	6.813	+0.388
204	8.113	8.165	8.138	8.122	8.130	8.072	8.030	7.987	7.593	—0.160

COMPARISON OF HYDROGEN AND QUINHYDRONE ELECTRODES

After studying the effect of these factors on the fluctuation in the pH values of several soils, quinhydrone electrode readings were compared with those obtained with the regular hydrogen electrode method. In order to obtain satisfactory results with the quinhydrone electrode a definite laboratory technic is evidently necessary. The technic used in this laboratory is as follows.

A 1:1 soil-water ratio is used as was suggested in an earlier publication (2) and which has been recommended by other investigators (6,7,10). Twenty grams of soil and 20 cc of distilled water are placed in a 100-cc beaker. A smaller amount of soil may be used, but this makes a convenient amount for stirring. About 0.10 gram of powdered quinhydrone is added. The mixture is stirred with a glass rod and the platinum electrode and the agar bridge from the cell are immersed in the soil suspension. The suspension is mechanically stirred for 0.5 minute and the pH readings taken. A saturated calomel cell is used as the reference electrode. Contact with the soil suspension is accomplished by a saturated KCl-agar bridge. The end of the bridge that is placed in the soil suspension is *always* kept in a saturated KCl solution when it is not in use. A bright platinum cone is used as the metallic electrode. The care of this electrode cannot be overemphasized. Each day before using, *it should be cleaned in a hot chromic acid mixture, rinsed with distilled water, and heated to redness in an alcohol flame.* When not in use, it should be kept in distilled water and not allowed to stand in the dust and fumes of the laboratory.

In some cases a mechanical stirrer is not available and stirring is almost impossible. Under these conditions a French square bottle can be used to advantage in place of a small beaker. Ten grams of soil and 10 cc of water are placed in the bottle with about 0.05 gram of quinhydrone and shaken thoroughly. When the electrodes are immersed in the suspension the bottle is shaken again. Readings are made in about 0.5 minute. This technic can easily be carried out in the field as well as in the laboratory. In order to check the accuracy of the electrodes, a solution with a standard pH or a control soil with a known pH is used.

If a potentiometer having a relatively insensitive galvanometer is used, that is, if at the end point the deflection of the galvanometer needle does not change direction with a small change in the resistance in the potentiometer, this end point should always be approached from the same direction to obtain comparable results.

A comparison of the pH values of various soils obtained with the quinhydrone method, using the technic described above, with those obtained with the hydrogen electrode is given in Table 8. The soil-water ratio with the hydrogen electrode was 1:5. These results are indicative of the close agreement between the two methods. In all of the experiments in this study the first reading with the quinhy-

drone electrode, taken at least within one minute after the electrodes were immersed, compares the best with the hydrogen electrode reading.

Biilmann states that the quinhydrone method is not a universal method. There are cases where the quinhydrone electrode is more applicable than the hydrogen electrode, and vice versa.[4] There are conditions where neither electrode is satisfactory. When the results with the quinhydrone and hydrogen electrodes do not agee very closely, it is a question of which electrode is wrong. When one thinks of the variations in reaction of the same soil from day to day and from one place to another, an expression of the pH value to the second decimal place hardly seems plausible for practical purposes.

TABLE 8.—*pH values of various soils as measured by the quinhydrone and hydrogen electrodes.*

Soil No.	Soil type	Depth in inches	pH values: Quinhydrone electrode, Beaker, stirred	pH values: Quinhydrone electrode, French square bottle	pH values: Hydrogen electrode, Beaker, stirred
105	Rittman silt loam . . .	1–3	3.99	3.95	4.05
150	Mahoning silt loam. . .	10–13	5.10	5.13	5.14
145	Rittman silt loam . . .	41–48	6.08	6.16	6.07
178	Palmyra gravelly loam	2–3	6.58	6.52	6.40
204	Canfield silt loam.	60–65	8.10	8.25	8.11
135	Rittman silt loam	1–2	5.89	5.99	5.73
119	Ellsworth silt loam . .	32–40	6.46	6.41	6.45
173	Schoharie silt loam . . .	8–11	6.11	6.04	5.94
175	Schoharie silt loam . . .	15–24	8.12	8.12	8.15
165	Tyler silty clay loam. .	6–10	5.41	5.51	5.54

Even if the quinhydone electrode values may vary 0.20 in pH from those obtained with the hydrogen electrode, its simplicity makes it more applicable for measuring the reaction of soils.

SUMMARY

A study was made of various factors that may influence the drift in potential of the quinhydrone electrode.

[4]Upon determining the reaction of four soils from Kentucky with the quinhydrone electrode, very large changes in the measured pH values were observed. These fluctuations were undoubtedly due to chemical effects produced by some constituent of these soils on the components of the quinhydrone. The changes in the measured pH values of the Greenville silt loam were as follows:

	Instantly	1 minute	5 minutes	10 minutes
pH.	5.20	5.92	6.30	6.30

The pH value of this soil measured with the hydrogen electrode was pH 5.14. Even with these rapid changes in the measured pH values, the reading taken immediately after the addition of the quinhydrone agrees fairly well with the hydrogen electrode reading.

The fluctuation in pH values measured with the saturated calomel, N/20 potassium acid phthalate, and 0.01N HCl plus 0.09N KCl electrodes varied with the different soils. The calomel cell is preferred because of its stability.

There were no significant differences in the results obtained with the platinum cone, platinum foil, platinum gauze, and gold foil electrodes. The platinum cone has the advantage of being more rigid and compact.

Mechanical stirring reduced the deviations in the pH values of these soils.

The lower part of the soil suspensions tended to be more acid than the upper.

Recrystallized quinhydrone did not materially affect the changes in pH when compared with a good c.p. commercial product.

Passing CO_2 -free air or hydrogen through the soil suspension did not influence the deviations in pH.

Allowing the soil-water mixture to stand over night did not reduce the fluctuations in the pH values.

A definite technic is necessary for obtaining satisfactory results with the quinhydrone electrode. The care of the metallic electrodes is of prime importance. A solution of definite pH or a control soil is used to check the accuracy of the electrodes.

The first reading, made at least within one minute after the electrodes are immersed in the soil suspension, is the more nearly correct reading.

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ELECTRODIALYSIS OF SOILS:

III. EFFECT OF DIFFERENT FERTILIZER TREATMENTS OF SOILS ON THE BASES AND ACIDS EXTRACTED BY ELECTRODIALYSIS[1]

Harry Humfeld[2]

INTRODUCTION

Ever since the earliest investigations along soil fertility lines, attempts have been made to devise methods which would show the amounts of the necessary plant-food constituents present in the soil in an available form.

At first it was thought that a determination by chemical analysis of the presence in the soil of the total amounts of the different elements used by plants would indicate the amounts available. But it was soon found that, although an element needed for plant growth might be present in the soil in a considerable amount, this would not necessarily mean that there would be an adequate amount present in such a form as to be available.

In recent years many experiments have attempted to give an insight into the state in which the various elements must occur to be available to plants. It has been shown that plant food must be in solution to be able to pass through the membranes of the root hairs into the cell sap of the plant. Hence it has seemed evident that the plant food must be in solution in the soil moisture in order to be of use to plants. This has led to the development of methods for the extraction of available plant foods by the use of water.

Among these methods the more important ones involve leaching the soil with water, or shaking the soil with certain amounts of water for different lengths of time. It has been shown, however, that these methods fall short of the objective sought, for it is known that plants take up much larger amounts of certain elements than are found to be present when these water extracts are analyzed. The chief

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objection to the water extract methods is that they do not give the true soil solution and hence they may not give a correct indication of the amount of plant foods present in the soil in an available form.

Several methods have been devised which are designed to extract the soil solution as it exists in the soil. They consist principally of applications of great pressure or the use of some liquid for displacement of the soil solution. Water, alcohol, and paraffin have been used, but no method devised has given a complete displacement of all of the moisture present. These methods have also given extracts containing much smaller quantities of available elements than are known to be taken up by plants. Other investigators have resorted to treatment of the soil with acids of different strengths, in order to extract the available plant foods, and many methods are available which vary only in the kind and strength of the acids used, and in the time and manner of treatment.

Some investigators using these methods have secured good correlation between the content of available plant food and crop production, while others working with the same methods, have failed to obtain any correlation.

Quite recently the theory of base exchange has come to be considered of importance from the soils standpoint, and it is now believed that the study of base exchange may throw considerable light on the question of the availability of elements necessary for plant growth.

Base exchange in soils was discovered by Way (6)[3] in 1852. He showed that, if a soil were treated with a solution of ammonium salts, a part of the ammonia was absorbed and an equivalent quantity of other bases was brought into solution. However, the importance of this discovery was not realized until comparatively recently. It was brought to the foreground with the publication of the work of Gedroiz (1) and Hissink (2). Gedroiz stressed the importance of base exchange in the formation and reclamation of alkali soils. Hissink, studying soils in Holland, which had been reclaimed from the sea, concluded that in such cases the poor structure might be due to the presence of sodium as the principal exchangeable base. He found that 97% of the bases, which were exchanged when equilibrium was reached, were replaced within five seconds. From this he concluded that these replaceable elements must be in a form readily available to plants. If this conclusion is logical, any method which is intended to determine the amounts of elements available to plants must take into account the exchangeable bases.

[3]Reference by number is to "Literature Cited," p. 1159.

If the exchangeable bases are available to plants, as is now believed, they probably become available in the following manner. It may be assumed that there exists a state of equilibrium between the absorbed elements and the elements actually present in solution in the soil moisture. When the plant takes up a certain amount of the elements from the soil solution, this equilibrium is disturbed and, in order again to bring about a state of equilibrium, some of the absorbed elements go into solution. Hence the concentration of any one element in the soil solution at any time is dependent primarily upon the amount present in the absorbing complex.

The ratio of the amounts of absorbed elements to the amounts of the same elements in solution will depend upon a number of factors, among which the more important are the amount of moisture in the soil, the texture of the soil, the temperature, the solubility of the particular element, the concentration of the other elements in the soil solution, and the amount and proportion of the elements in the absorbed state.

The different elements needed by the plant must be present in the soil solution in a certain concentration for maximum crop production. If the amount of any element present in the soil solution falls below the proper concentration, then that element becomes what is called a "critical" element in crop production and additions of this element, or of other elements which can replace it from the absorbing complex, will give increases in crop yields.

The availability of the various elements to plants might be studied by disturbing this equilibrium by continually removing the elements in the soil solution by leaching with water and analyzing the filtrates. However, the concentration of salts in the filtrates is low and the amounts of the different elements present are too small to be determined accurately by ordinary quantitative analysis. Treatment with neutral salts hastens the removal of the available elements and in this way all of the replaceable bases can be obtained in a comparatively short time.

Electrodialysis is based on the same principle. When an electrical current is passed through a sample of soil to which distilled water has been added the elements in the soil moisture are removed in much the same way in which the plant removes them from solution; the cations moving to the negative pole, and the anions moving to the positive pole. In this way the equilibrium is disturbed and as a consequence the absorbed elements are brought into solution. By the proper use of semi-permeable membranes the liberated ions are

continually removed from contact with the soil and presently the soil becomes completely unsaturated with respect to these elements and hydrogen, obtained from the hydrolysis of the water, acting as a base, takes the place of the cations.

The investigators mentioned, as well as all the others who have studied the replaceable bases in soils, have shaken or leached the soil with neutral salts in order to extract these bases. It remained for Mattson (5) to compare the results of neutral salt extractions with those obtained by electrodialysis. He found that the two methods agreed very well. The method which should be used would then be that one which is the more convenient and expedient.

It is believed that there are certain advantages in using electrodialysis. Some of these are as follows: (a) Cations and anions are completely separated so that each can be studied independently, (b) the total amount of bases and of acids extracted can readily be determined by simple titration with an acid and a base of known normality, (c) the degree of saturation of the soil can be determined, (d) a totally unsaturated soil is obtained which can be used for further studies, and (e) only the elements extracted from the soil are present in the solutions to be analyzed.

In the work reported in the following pages, the procedure outlined by Mattson was taken as a starting point. As the work progressed, it was found that certain modifications in the method were very desirable. These have been outlined and discussed. The use of the method in the study of availability and the effect of different treatments of the soil on the results obtained has been studied and will be discussed.

A literature review of the subject and the development of the procedure used in the work reported in the experimental part of this paper has been published previously by Humfeld and Alben (3, 4).

This paper gives an application of the method to investigations of soils under different treatments.

USE OF DIFFERENT SOILS

In order to obtain some information as to the comparative amounts of replaceable bases present in different soils, samples of soils which would presumably show considerable differences were subjected to electrodialysis. The soils used were:

1. A virgin Carrington loam obtained from the Agronomy Farm of the Iowa Agricultural Experiment Station. This soil is a good fertile soil fairly well supplied with organic matter and produces

good crops without the use of artificial fertilizers, although applications of phorphorus give increases in crop yields. The soil had a pH of 4.8.

2. A Conover silt loam from an area west of Boone, Iowa. This soil is rather infertile, low in organic matter, responds to almost any kind of fertilizer treatment, is apparently low in all of the necessary plant foods, and had a pH of 5.2.

3. A peat from an area near Crystal Lake, Iowa. This soil contains 51% organic matter as determined by loss on ignition. This soil had a pH of 6.1.

A 100-gram sample of each soil was weighed out and placed in the dialyzer cell. A three-wire copper electrode was used for the cathode and a platinum gauze for the anode. The cooling system consisting of three glass grids was employed. The results are recorded in Tables 1, 2, and 3.

TABLE 1.—*Results of electrodialysis of Carrington loam.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
9	21	0.25	2.24	11.68
21	17	0.08	0.18	6.58
30½	17	0.10	0.22	2.81
44	21	0.10	0.14	0.57
		Totals	2.78	21.64

TABLE 2.—*Results of electrodialysis of Conover silt loam.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	21	0.26	0.57	4.88
9	21	0.08	0.20	1.79
21	22	0.06	0.19	0.66
45	20	0.04	0.12	0.31
		Totals	1.08	7.75

TABLE 3.—*Results of electrodialysis of peat.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
2½	40	2.31	6.57	15.92
5½	26	0.68	2.83	11.51
11½	18	0.18	1.65	10.09
22½	19	0.10	1.40	10.01
36½	19	0.10	1.18	10.42
47	20	0.12	0.89	11.13
60½	21	0.17	1.02	9.75
71½	20	0.28	1.03	9.73
83½	30	0.50	1.02	9.89
96½	23	0.38	0.61	7.26
107	28	0.30	1.03	2.89
120½	20	0.22	0.74	1.00
131½	20	0.18	0.50	0.19
144½	20	0.14	0.40	0.14
		Totals	20.87	109.96

The results show the great differences that may be found in different soils. The small amount of bases present in the Conover silt loam may have some connection with the low crop yields obtained on this type of soil. The large amounts of bases present in the peat soil might have been expected as it is well known that colloidal humus materials have a much greater absorbing capacity for replaceable bases than the colloidal mineral constituents.

The larger the amounts of replaceable bases present, the greater is the time required to effect complete replacement. However, satisfactory end points can be secured in any case.

EFFECT OF DIFFERENT TREATMENTS

Samples were taken in the spring either before any crops were planted or before the crops had made any appreciable growth. A series of five plats receiving different treatments under continuous corn since 1913 were used for the first trial. The treatments were as follows:

Plats 905 and 909 were untreated check plats.
Plat 906 received an application of 8 tons of farm manure once every four years.
Plat 907 received a similar application of farm manure plus ground limestone in accordance with the requirements indicated by a qualitative test of the soil for acidity.
Plat 908 received a treatment of ground limestone similar to plat 907.

Each plat was of one-tenth acre in size. Representative samples were secured by taking a sample in 10 places in each plat, mixing thoroughly, and sieving about 10 kg through a 10-mesh sieve. Samples of 100 grams each were weighed out and dialyzed. The dialysates were titrated with NaOH and HCl of known normality. The acid dialysates were titrated with NaOH to the color change of phenolphthalein. The basic dialysates were titrated with HCl, using methyl red as an indicator, adding a known quantity of HCl, using an excess sufficient to make the solutions distinctly acid, and making sure that all precipitates were dissolved. NaOH was then added until the methyl red changed from red to a brownish yellow.

The procedure described above was evolved as it was found that during the first stages $Ca(OH)_2$ and presumably also $Mg(OH)_2$ were precipitated, and that during the latter stages the presence of $Al(OH)_3$ and $Fe(OH)_3$ caused an absorption of the indicator, so that correct end points could not be secured. However, if a decided excess of acid was added and a back-titration was made with a base, both of these difficulties were overcome and satisfactory results could be secured.

Tables 4 to 9, inclusive, give the results secured in duplicate dialysis of the samples from each plat.

TABLE 4.—*Results of electrodialysis of soil of plat No. 905.*

Treatment: None

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	20	0.41	0.285	6.683
9	19	0.24	0.217	6.848
21	20	0.15	0.176	4.732
33	21	0.10	0.122	4.343
45	21	0.07	0.094	3.122
		Totals	0.894	25.728
		Duplicate		
3	22	0.40	0.298	6.684
9	20	0.26	0.190	6.844
21	20	0.16	0.176	5.166
33	20	0.10	0.094	3.136
45	21	0.07	0.094	2.514
		Totals	0.852	25.334

TABLE 5.—*Results of electrodialysis of soil from plat No. 906.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	21	0.48	0.393	6.250
9	21	0.28	0.230	6.657
21	20	0.14	0.186	4.619
33	18	0.08	0.122	2.977
45	18	0.08	0.122	2.988
		Totals	1.053	23.491
		Duplicate		
3	20	0.38	0.298	4.362
9	20	0.28	0.230	7.798
21	20	0.14	0.217	5.012
33	18	0.08	0.081	3.427
45	18	0.08	0.095	2.451
		Totals	0.921	23.050

TABLE 6.—*Results of electrodialysis of soil from plat No. 907.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	21	0.34	0.393	6.332
9	21	0.23	0.244	5.340
21	21	0.13	0.163	4.421
33	20	0.07	0.122	1.883
45	20	0.06	0.108	1.815
		Totals	1.030	20.791
		Duplicate		
3	22	0.35	0.338	5.903
9	21	0.23	0.244	5.903
21	21	0.13	0.190	4.877
33	19	0.07	0.122	1.693
45	20	0.06	0.095	1.896
		Totals	0.989	20.272

TABLE 7.—*Results of electrodialysis of soil from plat No. 908.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	21	0.31	0.338	6.074
9	19	0.17	0.203	4.985
21	20	0.11	0.163	2.804
33	20	0.06	0.108	1.374
45	19	0.05	0.081	1.293
		Totals	0.893	16.530
		Duplicate		
3	21	0.28	0.312	5.012
9	19	0.17	0.203	4.660
21	19	0.13	0.190	3.793
33	19	0.06	0.068	1.401
45	18	0.05	0.081	1.116
		Totals	0.854	15.982

TABLE 8.—*Results of electrodialysis of soil from plat No. 909.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	20	0.21	0.312	4.606
9	17	0.09	0.163	2.894
21	20	0.06	0.136	1.563
33	18	0.05	0.108	1.130
45	18	0.04	0.068	0.493
		Totals	0.787	10.686
		Duplicate		
3	20	0.18	0.298	4.121
9	17	0.09	0.163	2.772
21	20	0.06	0.122	1.753
33	18	0.05	0.108	0.788
45	18	0.04	0.068	0.074
		Totals	0.759	10.074

TABLE 9.—*Comparison of results of electrodialysis of soils cropped to continuous corn under different treatments.*

Plat No.	Treatment	Bushels per acre, 1927	Total acids Milli-equivalent	Total acids Average	Total bases Milli-equivalent	Total bases Average
905	Check	33.3	0.894 0.852	0.873	25.728 25.334	25.531
906	Manure	34.7	1.053 0.921	0.987	23.491 23.050	23.270
907	Manure and lime	37.3	1.030 0.989	1.009	20.791 20.273	20.531
908	Lime	32.0	0.893 0.854	0.873	16.530 15.982	16.256
909	Check	25.9	0.759 0.787	0.773	10.074 10.686	10.380

The results show that good agreements can be secured by dialysis of duplicate samples of the same soil. It will be noted that there was a great difference in the amount of bases extracted from the

samples from the different plats. There was a decrease from plat 905 to plat 909. A study of the texture of the soil and the topography of the plats shows very plainly the reason for this variation.

The plats are located on a slope, the upper end of which is occupied by plat 909, each succeeding plat being lower than the preceding one. Plat 909 is almost a sandy loam, while the texture becomes finer down the slope, plat 905, the lowest plat, having the texture of a silt loam. This explains adequately the variation in the amounts of replaceable bases in the different plats. If the amount of bases from each plat is shown graphically and a progressive average is used for the purpose of determining the effect of treatment on the replaceable bases, the results show that there is a definite increase in replaceable bases due to treatment. In the same way it can be shown that the treatments also caused an increase in extractable acids.

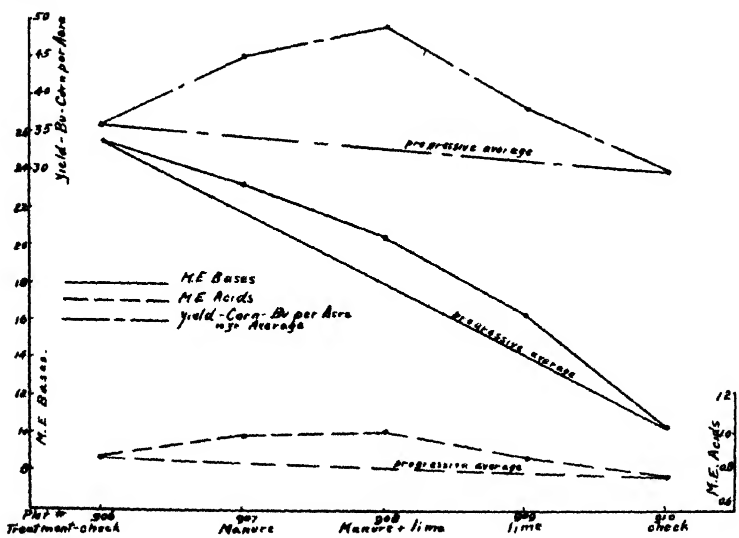

FIG. 1.—Comparison of average yield of corn with bases and acids extracted by electrodialysis.

If the acids and bases extracted are available to plants as plant foods, the increase should reflect itself in increased yields of crops.

The yield of corn in bushels per acre in relation to the acids and bases extracted is shown in Fig. 1. The graph shows very plainly that a positive correlation exists and that in this case the increase in acids and bases was an indication of increased crop yields.

The results show that great care should be taken in selecting a series of plats for experimental purposes. They also suggest that

electrodialysis might be used as an aid in the determination of the suitability of certain soil areas for experimental purposes.

The next series of plats used in this investigation consisted of six plats, Nos. 1000 to 1005, inclusive, which form part of one series of plats in a five-year rotation. The sequence of crops in the rotation has been oats, alfalfa five years, corn, oats, clover, wheat, and corn.

The treatments were as follows

Plat No.	Treatment
1000	Check
1001	Manure
1002	Manure and lime
1003	Manure plus lime plus rock phosphate
1004	Manure plus lime plus superphosphate (acid phosphate)
1005	Check

TABLE 10.—*Results of electrodialysis of soil from plat No. 1000.*

Time in hours	Temperature °C	Ammeter reading in amperes		Acids Milli-equivalent	Bases Milli-equivalent
3	21	0.32		0.352	5.977
9	20	0.18		0.190	5.481
21	18	0.10		0.176	3.384
33	18	0.07		0.122	2.392
45	18	0.07		0.108	1.577
			Totals	0.948	18.811
		Duplicate			
3	21	0.34		0.366	6.595
9	20	0.17		0.244	4.904
21	17	0.10		0.176	3.349
33	18	0.07		0.122	2.021
45	18	0.07		0.095	1.444
			Totals	1.003	18.313

TABLE 11.—*Results of electrodialysis of soil from plat No. 1001.*

Time in hours	Temperature °C	Ammeter reading in amperes		Acids Milli-equivalent	Bases Milli-equivalent
3	17	0.27		0.268	4.892
9	17	0.19		0.227	5.273
21	16	0.10		0.247	3.277
33	16	0.08		0.103	2.721
45	16	0.06		0.103	0.696
			Totals	0.948	16.859
		Duplicate			
3	19	0.27		0.257	5.016
9	18	0.21		0.247	5.428
21	17	0.10		0.227	3.172
33	16	0.08		0.165	2.692
45	17	0.06		0.134	0.840
			Totals	1.030	17.148

TABLE 12.—*Results of electrodialysis of soil from plat No. 1002.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	20	0.37	0.381	6.692
9	17	0.20	0.268	5.959
21	17	0.10	0.257	3.115
33	16	0.08	0.165	2.466
45	16	0.06	0.113	0.490
		Totals	1.184	18.722
		Duplicate		
3	22	0.37	0.381	6.814
9	19	0.20	0.247	5.848
21	18	0.10	0.216	2.558
33	17	0.08	0.145	2.280
45	18	0.06	0.113	0.983
		Totals	1.102	18.483

TABLE 13.—*Results of electrodialysis of soil from plat No. 1003.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	23	0.52	1.030	6.619
9	21	0.33	0.921	7.827
21	19	0.14	0.474	2.354
33	18	0.10	0.230	1.904
45	19	0.08	0.149	1.084
		Totals	2.804	19.788
		Duplicate		
3	23	0.54	1.016	7.182
9	21	0.32	0.840	7.594
21	19	0.14	0.488	2.284
33	18	0.10	0.244	1.893
45	19	0.08	0.149	0.846
		Totals	2.737	19.799

TABLE 14.—*Results of electrodialysis of soil from plat No. 1004.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	22	0.25	0.826	9.003
9	19	0.18	0.420	5.921
21	21	0.27	0.379	2.910
33	18	0.18	0.163	1.484
45	20	0.18	0.176	0.991
		Totals	1.964	20.309
		Duplicate		
3	23	0.18	0.786	8.653
9	21	0.16	0.406	6.104
21	20	0.17	0.379	1.925
33	19	0.11	0.203	2.483
45	20	0.10	0.163	1.645
		Totals	1.937	20.810

The rates of applications were as follows: Manure, 8 tons per acre once every four years; lime, according to lime requirement test; rock phosphate, 1 ton per acre once every four years; and superphosphate (acid phosphate), 200 pounds per acre annually.

The samples were taken as described previously, and samples were dialyzed in duplicate. Detailed results are given in Tables 10 to 16, inclusive

TABLE 15.—*Results of electrodialysis of soil from plat No. 1005.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	19	0.36	0.309	5.838
9	16	0.19	0.216	5.243
21	17	0.12	0.216	3.823
33	16	0.07	0.103	2.270
45	17	0.06	0.154	1.040
		Totals	0.998	18.214
		Duplicate		
3	22	0.36	0.309	5.683
9	18	0.19	0.206	5.240
21	19	0.12	0.196	3.906
33	17	0.07	0.144	1.426
45	19	0.06	0.113	1.158
		Totals	0.968	17.413

TABLE 16.—*Effect of different treatments or amounts on total bases and acids extracted by electrodialysis.*

Plat No.	Treatment	Bushels of wheat per acre, 1927	Milli-equivalents Acids Total	Acids Average	Bases Total	Bases Average
1000	Check	33.3	0.948 1.003	0.975	18.811 18.313	18.562
1001	Manure	34.9	0.948 1.030	0.989	16.859 17.148	17.003
1002	Manure+lime	36.2	1.184 1.102	1.143	18.722 18.483	18.602
1003	Manure+lime+rock phosphate	38.8	2.804 2.737	2.770	19.788 19.799	19.793
1004	Manure+lime+super-phosphate (acid phosphate)	41.7	1.964 1.937	1.950	20.309 20.810	20.569
1005	Check	28.3	0.998 0.968	0.983	18.214 17.413	17.813

The information given in Table 16 is graphically presented in Fig. 2. This again shows the correlation between replaceable bases and crop production.

An increase in replaceable bases was accompanied by an increase in crop production, except when manure was applied alone. In this case there was a decrease in the amount of bases extracted, although

there was a slight increase in yield. This is the only case where organic matter was applied without applications of inorganic fertilizers, such as lime and mineral phosphates. There may be a suggestion here that manure treatments enable the plant more effectively to deplete the soil of replaceable bases, and that some of the increases in yield are obtained at the expense of some of the exchangeable mineral constituents of the soil. This speculation opens up an interesting problem of the study of the effect of organic matter on the exchangeable bases over a period of years. Considerable study would be necessary before any conclusions could be drawn along this line, and the results shown here are only suggestive.

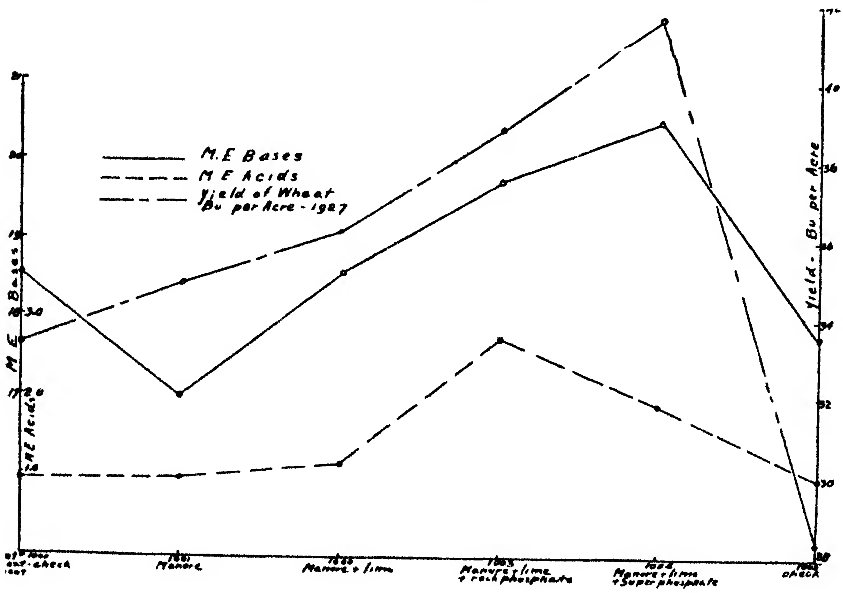

FIG. 2.—Comparison of yield of wheat with bases and acids extracted by electrodialysis.

A study of the curve of the milli-equivalents of acids extracted leads to a somewhat different conclusion. It will be noted that there is little variation in the amounts extracted, with the exception of the plats treated with rock phosphate and with superphosphate (acid phosphate), the increase being greater with the rock phosphate than with the superphosphate (acid phosphate) treatment. In this case there is, therefore, no correlation with crop production. The increases were so striking that it seemed possible that chemical analyses of the solutions might show the reason for the results.

Chemical analyses were made and the results will be reported later. First, however, it seemed desirable to confirm the results obtained by

TABLE 17.—*Results of electrodialysis of soil from plat No. 1024.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	20	0.30	0.566	11.428
9	21	0.30	0.257	7.977
21	20	0.21	0.268	3.483
33	19	0.15	0.165	2.742
45	19	0.13	0.134	1.852
		Totals	1.390	27.482
		Duplicate		
3	21	0.10	0.474	9.632
9	22	0.30	0.288	8.652
21	22	0.17	0.278	4.218
33	24	0.15	0.196	3.481
45	21	0.09	0.124	1.792
		Totals	1.360	27.775

TABLE 18.—*Results of electrodialysis of soil from plat No. 1025.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	22	0.68	0.525	8.491
9	18	0.42	0.371	10.176
21	17	0.30	0.330	6.722
33	15	0.09	0.134	3.115
45	15	0.06	0.144	2.785
		Totals	1.504	31.289
		Duplicate		
3	24	0.72	0.515	9.107
9	20	0.42	0.371	10.382
21	18	0.27	0.371	5.681
33	17	0.11	0.144	2.837
45	16	0.06	0.144	2.136
		Totals	1.545	30.143

TABLE 19.—*Results of electrodialysis of soil from plat No. 1026.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	21	0.65	0.639	10.110
9	18	0.45	0.391	10.926
21	18	0.35	0.412	11.926
33	17	0.19	0.278	4.030
45	18	0.09	0.196	4.306
57	19	0.11	0.154	3.339
69	19	0.10	0.072	1.058
		Totals	2.142	45.695
		Duplicate		
3	25	0.67	0.721	11.009
9	20	0.50	0.412	11.485
21	21	0.35	0.412	11.505
33	17	0.20	0.268	3.503
45	17	0.09	0.196	3.782
57	19	0.13	0.144	2.484
69	20	0.11	0.113	1.305
		Totals	2.266	45.073

similar tests on another series of plats which have received identical treatments and are under the same rotations, but which are located on a different soil type and were under a different crop. If the results obtained on this series should confirm the results previously presented, the final conclusions would have considerably more weight. In this series the soil is a Webster silt loam to a silty clay loam. It is considerably higher in organic matter and is practically neutral in reaction. The treatments are as follows:

Plat No.	Treatment
1024	Check
1025	Manure
1026	Manure plus lime
1027	Manure plus lime plus rock phosphate
1028	Manure plus lime plus superphosphate (acid phosphate)
1029	Check

The rates of applications were similar to those in the previous series. The crop grown was alfalfa. The samples were taken as described previously, and dialyzed in duplicates of 100 grams each. Detailed results are given in Tables 17 to 23, inclusive.

TABLE 20.—*Results of electrodialysis of soil from plat No. 1027.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	24	0.44	1.586	11.299
9	18	0.25	1.102	12.878
21	19	0.28	0.814	9.502
33	18	0.26	0.453	5.185
45	18	0.20	0.247	5.062
57	16	0.15	0.185	2.245
69	17	0.12	0.134	1.245
		Totals	4.521	47.425
		Duplicate		
3	25	0.36	1.586	11.070
9	19	0.26	1.102	11.603
21	21	0.28	0.826	9.990
33	21	0.31	0.484	5.400
45	22	0.22	0.268	4.359
57	19	0.17	0.185	1.748
69	20	0.14	0.123	1.086
		Totals	4.544	45.236

Table 23 and Fig. 3 show that there is considerable variation in the acids and bases extracted from the soils of the various plats. Again there was a gradual change in soil type from plat to plat and results similar to those observed in the electrodialysis of the continuous corn plats were secured.

TABLE 21.—*Results of electrodialysis of soil from plat No. 1028.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	22	0.54	1.051	12.890
9	20	41	0.659	13.550
21	21	0.55	0.577	10.964
33	18	0.21	0.309	2.999
45	20	0.16	0.226	4.348
57	17	0.15	0.196	3.318
69	19	0.12	0.144	2.659
		Totals	3.162	50.728
		Duplicate		
3	20	0.40	1.123	11.615
9	18	0.35	0.649	13.882
21	20	0.35	0.597	10.754
33	19	0.30	0.330	4.970
45	20	0.18	0.247	4.433
57	18	0.16	0.185	3.658
69	19	0.14	0.144	2.216
		Totals	3.275	51.528

TABLE 22.—*Results of electrodialysis of soil from plat No. 1029.*

Time in hours	Temperature °C	Ammeter reading in amperes	Acids Milli-equivalent	Bases Milli-equivalent
3	22	0.54	0.824	11.856
9	20	0.29	0.566	12.486
21	20	0.32	0.566	11.331
33	20	0.30	0.319	3.833
45	19	0.17	0.227	4.495
57	18	0.15	0.154	3.277
69	18	0.12	0.124	1.598
		Totals	2.760	48.876
		Duplicate		
3	23	0.34	0.793	10.916
9	20	0.30	0.566	12.225
21	22	0.28	0.587	11.846
33	22	0.31	0.360	4.577
45	21	0.17	0.247	4.586
57	18	0.14	0.144	2.917
69	17	0.12	0.113	1.845
		Totals	2.810	48.912

In this case the soil varies from a Webster silt loam on plat 1024 to a Webster silty clay loam on plat 1029. The increase in clay and presumably colloidal matter shows its effect on the quantity of extractable bases. In this instance, the two checks, which are located at the two opposite ends of the series, contained 27.628 and 48.894 milli-equivalents of bases per 100 grams of soil, respectively. However, it may be assumed that the change in soil type is uniform, and if a progressive average is taken, which in the graph is indicated by

the straight line connecting the two checks, it will be noted that the same conclusions can be drawn as in the previous series, namely, that except for the plat receiving manure alone, the increase in bases was accompanied by an increase in yield.

In the case of the acids extracted, the same was true, except that the increase of the rock phosphate treated plat was much greater than the increase on the superphosphate (acid phosphate) treated plat; again confirming the results obtained in the previous series.

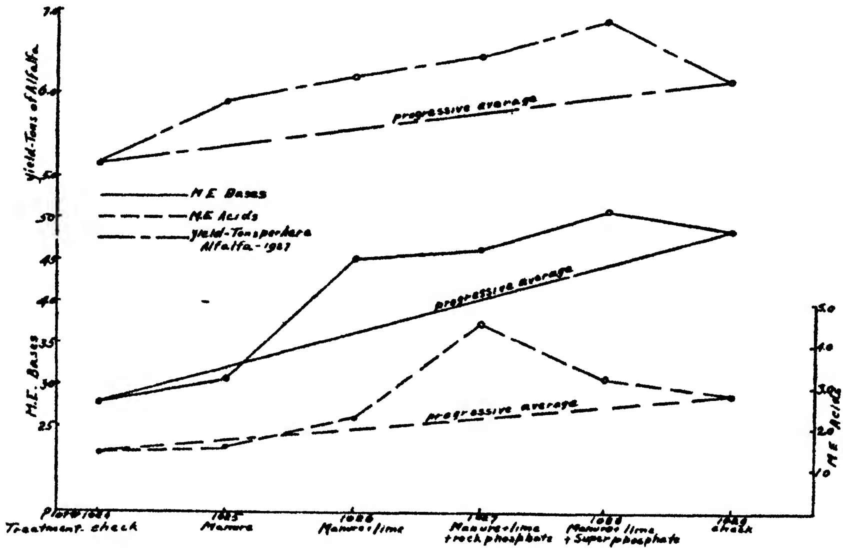

FIG. 3.—Comparison of yield of alfalfa with bases and acids extracted by electrodialysis.

TABLE 23.—*Comparison of results of electrodialysis of soils from plats in alfalfa under different treatments.*

Plat No.	Treatment	Tons per acre for 1927	Total acids Milli-eqiuvalent	Total acids Average	Total bases Milli-equivalent	Total bases Average
1024	Check	5.15	1.390 1.360	1.375	27.482 27.775	27.628
1025	Manure	5.90	1.504 1.545	1.524	31.289 30.143	30.716
1026	Manure and lime	6.20	2.142 2.266	2.204	45.695 45.073	45.384
1027	Manure+lime+rock phosphate	6.45	4.521 4.544	4.532	47.425 45.236	46.330
1028	Manure+lime+super-phosphate (acid phosphate)	6.90	3.162 3.275	3.218	50.728 51.528	51.128
1029	Check	6.20	2.760 2.810	2.785	48.876 48.912	48.894

It would seem that a chemical analysis of the acids extracted from the sample of soil from each plat would probably show the reasons for this considerable variation. Table 24 gives the results of the analyses obtained from the solutions from the soils of plats 1000 to 1005, inclusive.

TABLE 24.—*Analysis of the acid extracts.*

Plat No.	Treatment	Milli-equivalents Cl	S	P	N	Total acids
1000	Check	0.125	0.244	0.383	None	0.975
1001	Manure	0.100	0.201	0.335	None	0.989
1002	Manure+lime	0.127	0.240	0.447	None	1.143
1003	Manure+lime+rock phosphate	0.140	0.227	2.285	None	2.770
1004	Manure+lime+superphosphate (acid phosphate)	0.140	0.339	0.975	None	1.950
1005	Check	0.125	0.227	0.352	None	0.983

The results show very definitely the effect of the treatments. In the case of the phosphate treatments they were very striking. The rock phosphate caused a considerably greater increase than the superphosphate (acid phosphate), although both were very definite. The latter caused an appreciable increase in the sulfate. It is suggested that the increase in available sulfur may be one of the reasons why superphosphate (acid phosphate) gives greater returns in increase in yield than rock phosphate. It will be seen that the sulfate in the rock phosphate treated plat is as low as the check. No nitrates were found to be present in any of the solutions, chlorine did not vary to any extent, and is not usually considered important.

The milli-equivalents of acids unaccounted for in the analysis are probably organic acids, as all of the solutions had a definite brownish color and an organic residue was left on evaporation. No effort was made to analyze for any of the organic constituents.

An analysis of the bases shows that calcium predominated greatly, that considerable magnesium was present, that a determinable quantity of aluminum was present, that iron was present in a much smaller quantity, and that potassium was present in comparatively small amounts. Only traces of sodium could be detected. No satisfactory test for manganese was obtained.

SUMMARY

Advantages of electrodialysis of the soil as compared to the determination of replaceable bases by the neutral salt method are given. Results obtained from the dialysis of three widely different soils show that satisfactory end points were secured with each soil. The method outlined was used in a study of soils of different types and receiving different treatments. The results show:

1. That fertilizer treatments over a term of years have a measurable effect on the amounts and kinds of extractable acids and bases.

2. The effect of treatments of rock phosphate on the phosphorus and of superphosphate (acid phosphate) on the phosphorus and sulfur were especially striking.

3. Applications of farm manure seemed to cause a slight decrease in the total bases extracted.

4. A change of soil type within a range of plats may have a greater effect on the amounts of extractable acids and bases than any of the treatments.

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THE QUALITATIVE AND QUANTITATIVE DETERMINATION OF REPLACEABLE SODIUM IN ALKALI AND NON-ALKALI SOILS[1]

R. H. BRAY[2]

Until Barber and Kolthoff (1)[3] published their method for the rapid determination of sodium none was available for the extensive study of replaceable sodium in soils because of the time-consuming character of the method necessitating the separation of potassium.

In their method the sodium is precipitated in the presence of most other bases by means of a uranyl zinc acetate reagent. It comes down as a triple salt which has the composition $(UO_2)_3Zn \cdot Na(CH_3COO)_9 \cdot 6H_2O$ and contains 1.495% sodium.

Their preparation of the reagent is as follows:

A. Uranyl acetate		B. Zinc acetate	
($2 H_2O$)	10 grams	($3 H_2O$)	30 grams
Acetic acid, 30%	6 grams	Acetic acid, 30%	3 grams
Water to make	65 grams	Water to make	65 grams

"After the salts in A and B are dissolved by warming, the solutions are mixed and allowed to stand for twenty-four hours. The precipitate of uranyl zinc sodium acetate is filtered off and a solution is obtained that is saturated with the triple salt due to the sodium contained in the chemicals which go to make up the reagent."

Ten cc of the reagent are used to precipitate the sodium from 1 cc of the unknown solution. The precipitate is washed first with the reagent, then with alcohol and ether.

Since sodium may be determined by this method in the presence of calcium, magnesium, and small amounts of potassium, it is especially useful in base exchange work.

This paper will present the results obtained in the application of Barber and Kolthoff's method to the qualitative and quantitative determination of replaceable sodium in alkali as well as non-alkali soils.

SODIUM IN PURE NaCl

The method of Barber and Kolthoff was followed closely in some determinations made on pure NaCl as a means of getting acquainted with the procedure. At first the dried NaCl was weighed by differ-

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[3]Reference by number is to "Literature Cited," p. 1166.

ence. Later a standard solution was made up and 25 cc were measured out by means of a standardized burette. This was evaporated to 1 cc and 10 cc of the reagent added. In all cases where only one-half hour was allowed for precipitation low results were obtained. A longer period of standing gave better results, as shown in Table 1.

TABLE 1.—*Determination of sodium as* $(UO_2)_3Zn\cdot Na(CH_3COO)_9\cdot 6H_2O$.

Grams of Na taken as NaCl	Hours of standing before filtering	Grams of precipitate	Grams of Na recovered	Error %
0.01050	0.5	0.6304	0.00942	—10.3
0.00207	0.5	0.1192	0.00178	—14.0
0.00587	17	0.3858	0.00577	— 1.7
0.00587	17	0.3877	0.00580	— 1.2
0.00587	41	0.3907	0.00584	— 0.5
0.00587	41	0.3929	0.00587	0.0
0.00587	41	0.3913	0.00585	— 0.3
0.00587	41	0.3916	0.00585	— 0.3
0.00587	65	0.3944	0.00590	+ 0.5
0.00587	65	0.3927	0.00587	0.0
0.00587	96	0.3907	0.00584	— 0.5
0.00587	96	0.3924	0.00587	+ 0.0
0.00587	120	0.3934	0.00588	+ 0.2
0.00587	120	0.3919	0.00586	— 0.2

QUANTITATIVE REPLACEABLE SODIUM

As a solution for leaching the soil a 1N neutral solution of ammonium acetate was chosen, since it is easily driven off before proceeding with the determination.

Twenty-five grams of air-dried, 10-mesh soil are mixed with a small amount of the ammonium acetate solution and well stirred. This is thrown on a Büchner funnel and leached with the solution under slight suction until 500 to 1,000 cc of leachate have been collected.

The leachate is evaporated to dryness, ignited to remove excess ammonium acetate, and taken up with a few cc of concentrated HCl. Water is then added, the HCl neutralized with a small excess of ammonia, and the solution heated to boiling. It is filtered into a volumetric flask, cooled, and made up to the mark.

The entire procedure is carried out in duplicate for each soil and only one aliquot is taken from each flask. The aliquot should be from one-fifth to one-tenth of the whole amount, depending upon the amount of replaceable sodium in the soil. The remainder of the solution may be used for the determination of other replaceable bases.

The aliquot is measured into a 50-cc beaker and evaporated to dryness. It is taken up with 1 cc of water, then 10 cc of the uranyl zinc acetate reagent are added and the solution is allowed to stand

for about two days. It is then filtered through a weighed asbestos gooch crucible, using suction. The precipitate is washed 5 to 10 times with 2-cc portions of the reagent, allowing the crucible to suck dry between each washing. In the same manner it is washed five times with 95% ethyl alcohol which has been saturated with the uranyl zinc sodium salt. The alcohol is washed out with ether and air is drawn through the crucible to dry it. The crucible is wiped clean and allowed to stand about 10 minutes before weighing.

TABLE 2.—*Variation in duplicate determinations of replaceable sodium in soil.*

Sample No.	Grams of precipitate No. 1	Grams of precipitate No. 2	Difference between duplicates, grams
11774	0.0812	0.0837	0.0025
11775	0.4571	0.4588	0.0017
11776	0.6194	0.6211	0.0017
11777	0.4531	0.4531	0.0000
11789	0.0120	0.0130	0.0010
11790	0.0438	0.0424	0.0014
11791	0.1049	0.1071	0.0022
11792	0.1205	0.1199	0.0006
11793	0.1127	0.1133	0.0006
Blank	0.0058	0.0052	0.0006
Blank	0.0051	0.0045	0.0006

Table 2 gives the results from the first soils tried by this method. Since the soils were not ground but were only put through a 10-mesh sieve, the duplicates check as closely as could be expected.

INFLUENCE OF SUCCESSIVE LEACHINGS

A series of soils was leached with 500 cc of ammonium acetate solution, the leachate removed, and a second 500 cc of leachate collected.

TABLE 3.—*Effect of successive leachings.*

Sample No.	Na in first 500 cc of leaching %	Na in second 500 cc of leaching %	Percentage of extracted Na found in second 500 cc of leaching
11789	0.0045	0.0002	4.2
11790	0.0228	0.0022	8.8
11791	0.0604	0.0022	3.5
11792	0.0689	0.0017	2.4
11793	0.0646	0.0015	2.2

Table 3 gives the results, which show that practically all of the replaceable sodium is obtained in the first 500 cc. These results check with those obtained by Kelly and Brown (3).

RECOVERY OF SODIUM ADDED AS NaCl

In one series of samples, a second aliquot was taken and a known amount of NaCl was added. The results are given in Table 4. The uniform recovery from soils containing such widely varying amounts of replaceable sodium eliminates any question of the presence in the solution of any unknown interfering substance.

TABLE 4.—*Recovery of sodium added as NaCl.*

Sample No.	Grams of precipitate from 5-cc aliquot	Triple salt equivalent of 0.00352 gram Na added to 5-cc aliquot, grams	Grams of precipitate from aliquot and added Na		Error
			Found	Calculated	%
11789	0.0120	0.2354	0.2465	0.2474	0.4
11789	0.0130	0.2354	0.2476	0.2484	0.3
11790	0.0438	0.2354	0.2847	0.2792	2.0
11790	0.0424	0.2354	0.2814	0.2778	1.3
11791	0.1049	0.2354	0.3420	0.3403	0.5
11791	0.1071	0.2354	0.3392	0.3425	1.0
11792	0.1205	0.2354	0.3548	0.3559	0.3
11792	0.1199	0.2354	0.3577	0.3553	0.7
11793	0.1127	0.2354	0.3486	0.3481	0.1
11793	0.1133	0.2354	0.3500	0.3487	0.4

QUALITATIVE TEST FOR REPLACEABLE SODIUM

For making the qualitative test, about 8 grams of soil are placed in a test tube with 1 gram of NH_4NO_3 and 25 cc of distilled water added. The mixture is well shaken and filtered into a second test tube, using a fair grade of quantitative filter paper. One cc of this solution is placed in a third test tube and 10 cc of the uranyl zinc acetate added. Within a few minutes a crystalline precipitate collects on the bottom of the tube if an appreciable amount of sodium is present.

The remainder of the extract can be used for a qualitative test for replaceable calcium. Work is now in progress to make this qualitative calcium test a convenient one for use in the field. Comparative results may be obtained by measuring the precipitate which settles in a 2- or 3-mm tube sealed on the bottom of a larger tube. Ammonium oxalate is used as the precipitating reagent, although other reagents giving insoluble calcium compounds can be used.

Table 5 gives the results of the qualitative sodium tests in comparison with the amount of replaceable sodium determined quantitatively. These results indicate that the test is positive for quantities as low as 0.02% of replaceable sodium.

TABLE 5.—*Results of qualitative and quantitative determinations of replaceable sodium and of pH values in various soils.*

Sample No.	Soil type	Horizon	Replaceable Na Quantitative %	Replaceable Na Qualitative	pH of soil
11774	120A	A1	0.0239	+	6.25
11775		B1	0.1474	++	7.55
11776		B2	0.2008	+++	8.59
11777		C1	0.1458	++++	9.00
11778		C2	0.1144	++++	9.15
11779		C3	0.0795	++	8.60
11788	120B	A1	0.0023	—	5.28
11789		A2	0.0045	—	6.16
11790		A3	0.0228	+	6.80
11791		B1	0.0604	++	8.00
11792		B2	0.0689	++	8.27
11793		C1	0.0646	++	8.46
11794		C2	0.0640	++	8.28
11780	120B	A1	0.0019	—	4.89
11781		A2	0.0016	—	4.86
11782		A3	0.0092	trace	5.25
11783		B1	0.0902	++	6.75
11784		B2	0.1261	++++	8.55
11785		C1	0.0563	+++	8.70
11786		C2	0.0828	+++	8.64
11787		Till	0.0640	++	8.72
11795	120A	A1	0.0014	—	5.26
11796		A2	0.0187	+	6.00
11797		B1	0.1399	+++	6.95
11798		B2	0.1752	++++	8.55
11799		B3	0.1399	++++	9.06
11800		C1	0.1263	++++	8.96
11152	120C	A1	0.0041	—	5.70
11153		A2	0.0100	trace	6.40
11154		B	0.0744	++	7.43
12018	66	A1	0.0008	—	6.63
Ewing 107	2	surface 7 inches	0.0023	—	7.17
Ewing 106	2	surface 7 inches	0.0024	—	4.50
Garden Prairie		surface 7 inches	0.0004	—	6.13
11988	41	A1	0.0000	—	6.15
11995	41	A1	0.0001	—	5.86
12069	18	A1	0.0000	—	5.83
12076	22	A1	0.0000	—	6.83
12096	56	A1	0.0000	—	6.60

TABLE 5.—*Concluded.*

Sample No.	Soil type	Horizon	Replaceable Na Quantitative	Replaceable Na Qualitative	pH of soil
25-0	Muscatine (41)	surface 7 inches	0.0024	—	——
25-1		surface 7 inches	0.0090	trace	——
25-3		surface 7 inches	0.0196	+	——
25-8		surface 7 inches	0.0700	++	——
Lizard		surface 7 inches	0.0018	—	8.40
Alkali spot		surface 7 inches	0.0540	+	7.82
Near alkali spot		surface 7 inches	0.0017	—	5.20

Since the object of this study was to determine the applicability of the method to soil investigations, the samples used were so selected as to provide a wide range in soil characteristics and particularly to include some soils in which sodium is an important factor to be considered.

The samples with numbers above 11000 were taken from the collection obtained in the regular soil survey type study carried on by the University of Illinois. Type 120 is the key number for alkali soils known as "slick spots," and the A, B, or C occurring after the sample number means that carbonates are present (HCl test) in the upper 10 inches, between 10 and 20 inches, or between 20 and 30 inches, respectively. The other soils used were selected as exhibiting none of the "slick spot" characteristics, and include both dark and light-colored soils.

The samples numbered 25-0, 25-1, 25-3, and 25-8, however, are the surface 7 inches of Muscatine silt loam which had been treated about three years previously in greenhouse pot cultures with none, 1,000, 3,000, and 8,000 pounds, respectively, of sodium silicate, per acre 2,000,000 pounds of soil.

The soil known locally as a "lizard" soil contains many calcium carbonate concretions and has a high pH, yet shows a very low percentage of replaceable sodium.

The "alkali spot" and "near alkali spot" are samples taken close together. The "alkali spot" grew sweet clover but no corn and gave a qualitative test for replaceable sodium. The "near alkali spot" grew corn but no sweet clover and gave no test for replaceable sodium but was higher in replaceable calcium content. The quantitative results later confirmed the qualitative tests.

The possibility of interfering substances has to be considered in every new application of a method. Barber and Kolthoff give results which indicate that the reagent is specific for sodium. The results in Table 5 seem to confirm this since with some soils little more than a blank is obtained, while other soils give high results. The results are

consistent with what is known about the soils. Wherever the characteristics of "slick spots" are found, the pH is high as is also the content of replaceable sodium, but of the soils examined having a pH of 7 or more, only those showing "slick spot" characteristics in the field contain appreciable amounts of replaceable sodium, even though carbonates are abundant. Some of the sodium here reported as replaceable is probably soluble in water, as indicated by previous tests. The pH determinations were made by means of the hydrogen electrode (2).

SUMMARY

Barber and Kolthoff's method for the rapid determination of sodium has given satisfactory results when applied to replaceable sodium in soils.

A qualitative test for replaceable sodium is proposed which is senstitive to amounts as low as 0.02% replaceable sodium.

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THE DISAPPEARANCE OF NITRATES UNDER TIMOTHY[1]

L. G. JONES[2]

Investigations at the Cornell University Fxperiment Station have shown that the nitrate content of the soil under timothy is uniformly low. When large quantities of sodium nitrate were applied to timothy sod nitrates practically disappeared from the soil within a comparatively short time. In view of the relatively small nitrogen requirement of the timothy plant, it appeared that the discrepancy was due either to a loss of nitrogen from the soil or to the conversion of nitrate nitrogen to protein or some similar form. It has been the purpose of the writer to determine, by direct experiment under controlled conditions, the ultimate fate of nitrate nitrogen when applied to soil under timothy.

REVIEW OF LITERATURE

Warington (14)[3] observed that the drainage water from the Broadbalk Field at Rothamsted contained much less nitrate nitrogen than was to be expected from the manure supplied and the crop reaped. At the same place a similar observation was made by Russell (11) who determined nitrates at the beginning and at the end of the growing season in fallow soil and in soil on which a crop was growing.

Leather (4), in India, working with lysimeter tanks, observed that nitrate nitrogen disappeared from the soil on which certain crops were growing. He explained the effect as due to the direct influence of living plants on the activities of soil organisms.

Lyon and Bizzell (5) determined the nitrate content of soil under timothy, corn, potatoes, oats, millets, and soybeans. It was found that under timothy the nitrate content was lower than under any of the other crops.

Deherain (2), using lysimeter tanks, found that the nitrogen in the drainage water plus nitrogen in crops from tanks growing certain crops, notably grasses, was less than that in the drainage water alone from the unplanted tanks. This observation was substantiated by the lysimeter work of Lyon and Bizzell (6) in which timothy and mixed grasses were used. The results indicated that there was a strongly repressive influence on nitrate production by timothy and

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[3]Reference by number is to "Literature Cited," p. 1175.

mixed grasses in spite of the fact that the grass contained less nitrogen than did the crops that had a smaller influence on nitrate formation. Bizzell (1) reported a rapid disappearance of nitrates when sodium nitrate was added to timothy sod in the early spring. From analyses of the crop the loss appeared to be due only and in part to the absorption of nitrogen by the growing crop. The experiment indicated that the discrepancy was not due to leaching nor to removal of nitrogen by denitrification, although the direct proof of the latter was lacking.

According to the work of Lyon and Bizzell (7), it appears that the depressing effect of the timothy persists in the soil after the removal of the crop. Timothy and alfalfa were grown for six years separately on the same type of soil. The soil was then kept bare of vegetation, during which time nitrates were determined. It was found that the alfalfa soil produced more nitrates than did the timothy soil. These results were explained by the work of Lyon, Bizzell, and Wilson (8, 9) on the basis of a difference in the nitrogen-carbon ratio of the roots.

Doryland (3) suggested that the disappearance of nitrates from a soil is due in part to the influence of organic residues which temporarily increase the soil micro-organisms. This point of view has been strengthened by the work of others, including Murray (10) who found that the nitrogen originally contained in the soil in the form of nitrates which were decomposed on the addition of straw was all recoverable as total nitrogen.

Wilfarth, Rohmer, and Wimmer (15) suggested that nitrogen may be lost from the plant through the leaves and roots. It seems questionable, however, whether this loss would be sufficient to account for the very considerable disappearance of nitrates which has been noted under grass plants.

This brief review of the effect of timothy on soil nitrates indicates that the nitrogen required by the crops is not always sufficient to account for the disappearance of added or original nitrate. That organic matter in general possesses the ability of reducing the nitrates of the soil by stimulation of bacterial growth has been established. On account of the relatively wide nitrogen-carbon ratio of the residues, it is quite conceivable that the constantly decaying roots of an old timothy sod would contribute to reduction of the nitrates. There seems to be no experimental evidence to show whether this explanation would be sufficient to account for the entire discrepancy. Conceding that the organic matter contributed to the soil by the timothy roots would probably cause the consumption of nitrates, it is still

possible that a portion of the nitrate nitrogen would be lost from the soil in the form of free or elemental nitrogen, either by denitrification in the usual sense or by loss through leaves of the plant as suggested by Wilfarth, Rohmer, and Wimmer.

PLAN OF EXPERIMENT

These experiments were designed to determine the ultimate fate of nitrates added to the soil; specifically, to ascertain to what extent the disappearance is due to growth of crop, conversion to forms of nitrogen retained in the soil, or to elimination of nitrogen from the soil by bacterial action and volatilization.

To exclude the possible loss of nitrates by leaching, the timothy was grown in watertight, earthenware pots. The capacity of each pot was approximately 3 gallons, the amount of soil necessary to fill them being approximately 12 kg. The soil was taken from the experimental field of the Cornell University Exepriment Station. It is classified as Dunkirk silty clay loam, a rather heavy soil practically free from stones. It has the following mechanical composition:

Fine gravel	0.40%
Coarse sand	0.63%
Medium sand	0.83%
Fine sand	1.85%
Very fine sand	12.90%
Silt	60.83%
Clay	22.63%

Nitrates were determined by the phenol-di-sulfonic acid method as described by Schreiner and Failyer (12). In order to simplify the comparisons, nitrates were calculated in terms of nitrogen and are designated in the tables as "nitrate nitrogen." Total nitrogen was determined by the official Gunning methods (13). All results are reported as pounds per acre of nitrogen on the basis of 2,500,000 pounds of soil per acre.

SERIES I

The data given in this experiment was obtained by W. C. Forbush in 1922 and has not previously been published.

The pots were filled with soil, brought to a moisture content of 20% dry soil basis, and one-half the entire number were seeded with timothy on July 28, 1922. The unseeded pots were treated in every other respect like the seeded pots. They are designated in tne tables as "bare soil." The soil in all pots contained 1 pound per acre of nitrate nitrogen. On September 28, 1922, certain of the pots received applications of 300, 600, 900, and 1,800 pounds per acre of

sodium nitrate, equivalent, respectively, to 47, 94, 141, and 282 pounds of nitrogen. Two and one-half months after application of sodium nitrate the timothy was removed from the soil and analyses made. Table 1 contains a summary of the results obtained, each result being the average of three similarly treated pots.

TABLE 1.—*Nitrate nitrogen in soil at beginning and nitrate nitrogen in soil and total nitrogen in crop after two and one-half months in pounds per acre.*

Treatment	1	2	3	4	5
Planted Soil					
Nitrate nitrogen in soil and $NaNO_3$ at beginning	1	48	95	142	283
Nitrate nitrogen in soil at end	2	2	10	5	90
Difference to be accounted for	0	46	85	137	193
Total nitrogen in crop	103	148	191	230	220
Excess in crop	103	102	106	93	27
Bare Soil					
Nitrate nitrogen in soil and $NaNO_3$ at beginning	1	48	95	142	283
Nitrate nitrogen in soil at end	90	127	147	156	276
Gain (+) or loss (—)	+89	+79	+52	+14	— 7

The figures in Table 1 show that the nitrogen in the crop was more than sufficient to account for the nitrate nitrogen that disappeared during two and one-half months. In fact, there appeared to be a production of approximately 103 pounds of nitrate nitrogen where the timothy was growing. The larger applications of nitrate, treatments 4 and 5, appeared to decrease the production of nitrates. In the bare soil, formation of nitrates was somewhat lower than in the cropped soil, and there was a decrease with increase in amount of applied nitrate. The data indicate that, at a certain nitrate content, an equilibrium is established in this soil beyond which no accumulation takes place. Since the timothy is constantly removing nitrate, the equilibrium is constantly being disturbed, and the balance sheet shows that the crop favors the formation of nitrates without necessarily being a direct stimulant. The results of this experiment do not show the depressive effect of timothy indicated by field observations. However, these results were obtained with timothy in the first period of its development and it is possible that its capacity for absorption of nitrogen during this stage of growth was greater than it would have been with more mature plants. It seemed desirable, therefore, to ascertain the effect of stage of growth of timothy on the nitrate content of the soil. Such a comparison is made in Series II.

SERIES II

In this experiment applications of the nitrate were made to timothy growing in pots that had been seeded five months before. The rates of application were 450, 900, and 1,800 pounds of sodium nitrate per acre, corresponding, respectively, to 74, 148, and 296 pounds per acre of nitrogen. Six months after this application the timothy (tops and roots) was removed and the total nitrogen content determined. Table 2 contains the data, each result being the average of four similarly treated pots.

A short time after the sodium nitrate was applied it was found necessary to cut the timothy. The amount of nitrogen contained in this cutting was subtracted from the total nitrogen in the crop during the entire experiment in order to show the amount of nitrogen absorbed after fertilization. However, this figure is not strictly correct as no analyses were made of the roots at the time of fertilization. The actual amount removed by the crop after fertilization, therefore, should be somewhat smaller than is shown in the table.

TABLE 2.—*Nitrate nitrogen in soil at beginning and nitrate nitrogen in soil and total nitrogen in crop after six months in pounds per acre.*

Treatment	1	2	3	4
Nitrate nitrogen in soil and $NaNO_3$ at beginning....	1	75	149	297
Nitrate nitrogen in soil at end....................	2	2	2	25
Difference to be accounted for....................	0	73	147	272
Total nitrogen absorbed by crop following fertilization	40	91	141	226
Nitrate nitrogen unaccounted for................	0	0	6	46

The figures in Table 2 show that a distinctly net disappearance of nitrates occurred only with the application of 1,800 pounds per acre of sodium nitrate. If analyses of the roots had been permissible at the time of fertilization, the net disappearance would have been somewhat larger than is indicated. In view of this possible larger discrepancy, it remains to be determined whether the nitrogen was retained by or lost from the soil. Table 3 contains an inventory of the total nitrogen of the soil and crop at the beginning and at the end of the experiment.

TABLE 3.—*Total nitrogen in soil and crop in pounds per acre.*

Treatment	1	2	3	4
Total nitrogen in soil and $NaNO_3$ at beginning.....	3,313	3,387	3,461	3,609
Total nitrogen in soil at end.....................	3,386	3,404	3,405	3,451
Nitrogen in soil gain (+) or loss (—).............	+73	+17	—56	—158
Total nitrogen in crops.........................	89	140	189	275
Net gain (+) or loss (—)......................	+162	+157	+133	+117

The data show that reduction of nitrates was not accompanied by a loss of nitrogen from the soil. In fact, there was a net gain of nitrogen in all cases, although this appeared to decrease as the application of the nitrate increased. Under the conditions of this experiment, it is evident that any disappearance of nitrates was due to conversion to some other form of combined nitrogen.

SERIES III

Since it appeared that timothy five months old did not produce a very decisive effect, it seemed desirable to determine whether a more mature crop would be more effective in the manner anticipated. Accordingly, sodium nitrate was applied to timothy that had been seeded 11 months before. Two and one-half months after the nitrate was applied the crop (tops and roots) was harvested and analyses made of the soil and crop. Table 4 contains a summary of the results.

TABLE 4.—*Nitrate nitrogen in soil at beginning and nitrate nitrogen in soil and total nitrogen in crop after two and one-half months in pounds per acre.*

Treatment	1	2	3	4
Nitrate nitrogen in soil and $NaNO_3$ at beginning....	2	76	150	298
Nitrate nitrogen in soil at end	5	5	5	104
Difference to be accounted for....	10	71	145	194
Total nitrogen absorbed by crop following fertilization	21	72	131	186
Nitrate nitrogen unaccounted for.................	0	0	14	8

Allowing for the normal variation incident to the methods of analysis employed, it appears that timothy 11 months old produced an effect of the same magnitude as that produced by the 5-months-old plants. To complete the comparison, an inventory of soil and crop nitrogen is given in Table 5.

TABLE 5.—*Total nitrogen in soil and crop in pounds per acre.*

Treatment	1	2	3	4
Total nitrogen in soil and $NaNO_3$ at beginning.....	3,313	3,387	3,461	3,609
Total nitrogen in soil at end.................... ...	3,387	3,300	3,299	3,410
Nitrogen in soil gain (+) or loss (—)............	+74	—87	—162	—199
Total nitrogen in crops.........................	110	161	220	275
Net gain (+) or loss (—).......................	+184	+74	+58	+76

As in Series II. the figures show a net gain of nitrogen during the course of the experiment. Comparing the results with the more mature plants in Series II and III with those of young plants in Series I, it appears that the older plants absorb much less nitrogen and are more likely to show the depressive effect anticipated. The

results, as a whole, are not in entire accord with the observations on field-grown timothy, reference to which has already been made in the review of previous work. It seemed desirable, therefore, to conduct an experiment with timothy sod grown in the field and then placed under the controlled conditions described in Series I, II, and III. An investigation of this kind is described in Series IV.

SERIES IV

For this experiment, one-year-old timothy sod was obtained from the field which furnished the soil for the previous investigations. This sod was carefully transferred to 3-gallon pots filled with soil and the same procedure followed as in Series II and III. Five months after the nitrate was applied, complete analyses were made of soil and crop (top and roots). The results are given in Table 6.

TABLE 6.—*Nitrate nitrogen in soil at beginning and nitrate nitrogen in soil and total nitrogen in crop after six months in pounds per acre.*

Treatment	1	2	3	4
Nitrate nitrogen in soil and $NaNO_3$ at beginning....	1	75	149	297
Nitrate nitrogen in soil at end	0	0	0	0
Total nitrogen absorbed by crops following fertilization	70	94	181	377
Excess in crop...	69	19	32	80

The data show that the nitrogen absorbed by the crop following the additions was more than sufficient to account for the disappearance of the nitrates. In this respect the results are similar to those obtained in Series I and are not in entire accord with those of Series II and III. With respect to the net gain of nitrogen, the figures are similar to those obtained in the previous experiments, as is shown in Table 7.

TABLE 7.—*Total nitrogen in soil and crops in pounds per acre.*

Treatment	1	2	3	4
Total nitrogen in soil and $NaNO_3$ at beginning.....	3,601	3,675	3,749	3,897
Total nitrogen in soil at end.....................	3,606	3,594	3,774	3,720
Nitrogen gain (+) or loss (—)..................	+5	—81	+25	—177
Total nitrogen in crops.........................	70	94	181	377
Net gain (+) or loss (—)......................	+75	+13	+206	+200

There is here no evidence of a net loss of nitrogen from the soil under the conditions of this experiment.

The experiments with timothy taken as a whole indicate that, with the exception of very large applications, the nitrate that disappears can be accounted for by the crop's requirements. Since this conclusion does not substantiate observations on the application of

sodium nitrate to timothy sod in the field, it seems pertinent to advance some explanation for the difference. The pot experiments herein described differed from the field experiments in three important respects. In the first place, leaching was prevented in the pots, while in the field observations the amount of nitrates carried down by drainage was not determined. It is doubtful, however, whether leaching would be responsible for the removal of significant amounts of nitrates from timothy sod.

In the second place, the pot experiments involved the careful determinations in all cases of the nitrogen absorbed and held in the roots as well as in the tops. The roots in all cases contained considerable quantities of nitrogen, in some cases as much as the tops. In the field observations to which reference has been made, no chemical analyses of the roots were made. The third difference pertains to the soil conditions under which the experiment was performed. In the field soil, a much more compact condition was obtained than it was possible to produce in pots during the comparatively short period of these experiments. It is difficult to estimate the effect of this difference in compaction. With this type of soil, numerous experiments have shown that it is difficult to duplicate the field compaction in pots by mechanical means after the soil has been subjected to the necessary disintegration for pot work. Considerable time is required before the original compaction can be restored. As a further contribution to the question of nitrogen economy, an experiment was made in which the soil was kept free form vegetation. This experiment is described in Series V.

SERIES V

The soil was placed in pots which were treated in every respect like those previously described except that no plants were allowed to grow. Six months after the application of sodium nitrate, the soil was examined for nitrates and total nitrogen. The results are given in Tables 8 and 9.

TABLE 8.—*Nitrate nitrogen in soil at beginning and after six months in pounds per acre.*

Treatment	1	2	3	4
Nitrate nitrogen in soil and $NaNO_3$ at beginning....	1	75	149	297
Nitrate nitrogen in soil at end....................	26	72	92	126
Nitrate nitrogen unaccounted for.................	0	3	57	171

TABLE 9.—*Total nitrogen in soil in pounds per acre.*

Treatment	1	2	3	4
Total nitrogen in soil and $NaNO_3$ at beginning	3,313	3,387	3,461	3,609
Total nitrogen in soil at end	3,290	3,368	3,368	3,654
Gain (+) or loss (—)	—23	—19	—93	+45

In all cases where nitrate was applied there was a disappearance of nitrates unaccounted for, the larger the application the greater the discrepancy. Determinations of total nitrogen showed a loss in three cases and a gain in one. The results are not entirely consistent, however the quantities reported lost are small and may easily be within the limit of experimental variation. The experiments as a whole indicate that, with this soil type, nitrate added to bare soil is more likely to be fugitive than when applied to soil growing timothy.

SUMMARY

A study in pots was made of the ultimate fate of nitrates when applied to Dunkirk silty clay loam soil growing timothy of different ages, and when added to similar soil kept free of vegetation. A complete inventory was kept of the income and outgo of nitrate and of total nitrogen. The experiments were conducted over a period of 14 months.

The results show that nitrates disappear in a comparatively short time when added to timothy sod. This disappearance during a given time was more complete from the soil growing timothy than from the bare soil. Where the crop was growing this disappearance, the largest application of nitrate excepted, was accounted for by the nitrogen taken up by the crop (roots and tops).

At certain stages of growth the crop contained considerably more nitrogen than was contained in the added nitrate. Considering the nitrogen of the crop as "conserved," there was a net gain of total nitrogen by the soil where timothy was growing. Although not entirely conclusive, the figures indicate that added nitrate may be lost from bare soil of this type by denitrification.

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PLANT CHARACTERS AND YIELD IN GRAIN SORGHUMS[1]

JOHN H. MARTIN[2]

Very few studies of the plant characters responsible for the yields of grain sorghums have been made. Growers differ in opinion regarding the relative productiveness of thin stands with large heads and thick stands with small heads.

Some correlations are presented here with the hope of throwing light on the interrelationships between yields and several important plant characters of grain sorghums.

Three sets of data have been used. The first is the measurements of the size of heads and stalks per acre in fields of milo and kafir in southwestern Kansas and northwestern Oklahoma in 1926. These data were obtained in connection with determinations of the losses in harvesting with headers and combines. The fields represented a wide range of crop development under similar environmental conditions and the yield differences were the result chiefly of soil moisture supply, stand of plants, weed control, and cultural methods.

Another set of data was obtained from the plats in the spacing experiments with grain sorghums at the U. S. Dry-Land Field Station, Woodward, Okla. These experiments were conducted during the period from 1917 to 1926, which included favorable, unfavorable, and average seasons. The variability in crop growth and yields from year to year was due chiefly to differences in soil moisture, while the plat yields in a given season were affected principally by soil variations and differences in stand and tillering. Diseases and insects apparently had little effect upon the yields. The results from the plats at Woodward are not a true random sample because several years' data are thrown together. However, they are uniform as to variety, fairly uniform as to soil and cultural conditions, and include a much wider range of variability in plant development than is possible within a given season. The combined data are representative of crop conditions and plant development which are likely to be encountered in the western grain-sorghum region where the moisture supply is the chief factor determining yields.

The relation of the plumpness and weight of seeds to the weight per bushel was determined from samples grown in environmental experiments at Amarillo, Texas, Chico, Calif., and Rosslyn, Va., during the years 1914 to 1919, inclusive.

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication August 27, 1928.

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The correlation coefficients obtained in the farmers' fields of milo and kafir are shown in Table 1. The milo fields consisted of the Dwarf and Standard varieties, which are identical except in relative length of internodes. The kafir fields used in the calculations were either of the Dawn variety or of similar dwarf, early, or medium-early strains of Blackhull kafir. The data show that the number of heads per acre is highly correlated with yield per acre, and that there is a considerable but much smaller correlation between the weight per head and yield in both milo and kafir. A better correlation than that shown exists between yield per acre and weight per head in both milo and kafir up to a weight of 15 pounds per 100 heads, but larger heads than this usually were obtained only where the yields had been reduced by thin stands.

The correlation between the weight per head and number of heads per acre is slight but tends to be negative. In general, the size of head is decreased as the number of heads is increased, but frequently abundant moisture increases both the size and number of heads and a deficiency of moisture decreases both. The high correlation between yield and number of heads per acre indicates the importance of getting a full stand.

TABLE 1.—*Correlation coefficients between yield, size of heads, and number of heads per acre in 49 fields of milo and 47 fields of kafir in southwestern Kansas and northwestern Oklahoma.*

	Correlation coefficient between			
	Milo (49 fields)		Kafir (47 fields)	
	Weight per head in pounds	Number of heads per acre	Weight per head in pounds	Number of heads per acre
Yield per acre (total weight of heads)..	0.466±.075	0.699±.049	0.338±.087	0.618±.061
Weight per head in pounds..........	———	—0.040±.096	———	—0.302±.089

The correlation coefficients determined from the plàt experiments at Woodward, Okla., are shown in Table 2. The variables used in the determinations are averages of all plants in individual or replicated plats. The yield of grain is highly correlated with the yield of stover in both varieties of kafir. There is a high correlation between yield of grain and number of heads in all three grain-sorghum varieties. There also is a high correlation between yield and size of heads (grain per head), except in Reed kafir which shows a zero correlation. The weight of grain per head in this variety, which produces few suckers, is determined chiefly by the stand of plants. Thin stands cause

TABLE 2.—*Correlations between certain plant characters and yields of grain and stover of Dwarf milo, Sunrise kafir, and Reed kafir grown in spacing experiments at Woodward, Okla.*

	Correlation coefficients (r) between: Yield per acre (stover)	Heads per acre	Grain per head	Height	Erect heads %	Weight per bushel in pounds
Dwarf Milo (50 Plats)*						
Yield per acre (grain)		0.661±.054	0.852±.026	0.903±.018	—0.573±.064	0.541±.075
Heads per acre			0.244±.090	0.767±.039	—0.042±.095	0.340±.094
Grain per head (pounds)				0.658±.054	—0.702±.048	0.520±.078
Height					—0.419±.079	0.601±.068
Erect heads, %						—0.226±.101
Sunrise Kafir (50 Plats)*						
Yield per acre (grain)	0.528±.069	0.540±.075	0.526±.069	0.841±.028		0.782±.041
Yield per acre (stover)		0.700±.049	0.057±.095	0.511±0.70		0.514±.078
Heads per acre			—0.287±.088	0.347±.084		0.128±.105
Grain per head (pounds)				0.681±.051		0.699±.055
Height						0.726±.050
Reed Kafir (25 Plats)						
Yield per acre (grain)	0.898±.019	0.625±.082	0.000	0.645±.079		0.504±.101
Yield per acre (stover)		0.613±.084	—0.010±.135	0.765±.056		0.365±.117
Heads per acre			0.707±.067	0.285±.124		—0.178±.131
Grain per head (pounds)				0.337±.120		0.688±.071
Height						0.574±.090

*40 plats for weight-per-bushel correlations.

larger heads but not in proportion to the spacing. The yields of Reed kafir show a sharp decrease with increased spacing and increased size of heads. The weight per bushel of grain is highly correlated with yield of grain and grain per head in all three varieties.

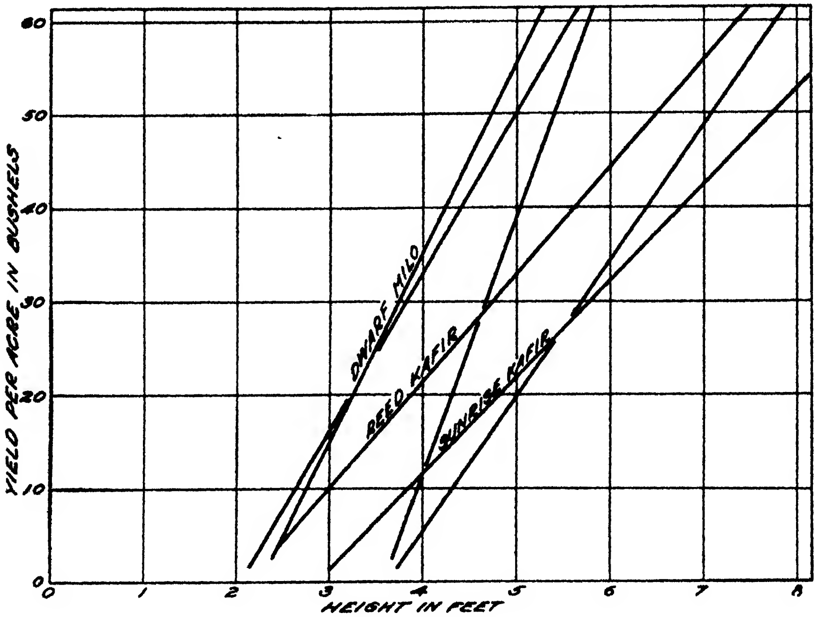

FIG. 1.—Regression lines, showing the relation between height and yield in Dwarf milo and Reed and Sunrise kafir.

The height of plant shows a very high correlation with grain yield in all three varieties. The correlation coefficients are higher than those between yield and the number of heads, size of heads, or weight per bushel of grain, the characters which, when multiplied together, constitute the yield. The height of plant in all varieties is positively correlated with both the number and size of heads and the weight per bushel of grain and, therefore, is a better measure of yield than any single yield character. The close relation between height and yield within a given uniform variety is illustrated by the regression lines in Fig. 1. The agreement between height and yield is not as close in Reed kafir as in the other varieties because the yields of that variety are affected more by differences in stand. Moisture and temperature conditions favorable for grain sorghums increase the number of tillers and heads per plant as well as the height of stalks. Conditions which favor elongation of the internodes of the sorghum stalk also favor an increase in the number and size of grains per head.

The yield of a field of a variety of grain sorghum appears to be approximately proportional to the height of plants when the normal height and yield of the variety are considered and the stand of plants in the field is ample. In general, the yield of a variety will be increased or decreased about 13 to 18 bushels per acre as the normal height is increased or decreased 1 foot.

The percentage of erect heads in milo is negatively correlated with yield of grain, number of heads, size of heads, height of stalks, and weight per bushel. The correlations between erect heads and number of heads and the weight per bushel are too small to be significant, however. The erectness of heads in milo is increased by deficient moisture and the crowding of plants, both of which reduce the yields of milo and affect the plant development adversely. Large heads are much more likely to be pendent than small heads.

The total weight per head and weight of grain per head showed almost a perfect correlation with a coefficient of plus 0.983 in 93 plats of Dwarf milo in spacing experiments at Woodward, Okla. The regression coefficient for weight of grain per head upon weight per head was 0.733, which is equivalent to an average shelling percentage of 73.3. The shelling percentages were somewhat smaller for very small and very large heads. Under favorable conditions, however, large heads of milo have shown shelling percentages in excess of 80.

The correlation coefficients between weight per bushel and weight per 1,000 seeds were plus 0.36 ± 0.10 in Dwarf milo and 0.76 ± 0.05 in Dawn kafir. In these data the milo ranged from 50 to 63 pounds per bushel and 20 to 45 grams per 1,000 seeds and the kafir from 54 to 63 pounds per bushel and from 15 to 25 grams per 1,000 seeds. The results show that the plumpness or weight of seeds within a variety is positively correlated with the weight per bushel. Although the seeds of kafir are smaller than those of milo, the weight per bushel usually is larger because the seeds are more rounded and pack together better.

SUMMARY

The yields of fields of grain sorghums are more closely correlated with the number of heads per acre than with the size of head or weight of grain per head. The correlation between the number of heads per acre and both the weight per bushel of grain and the average size of heads is either negative or not significant in the three varieties studied. The height of stalks within a given variety is highly correlated with grain yields. The yields of grain and stover in kafir are closely correlated.

The percentage of erect heads in milo is negatively correlated with yield and with the plant characters which determine yield.

The shelling percentage of milo heads of various sizes is nearly constant except for slightly lower shelling percentages in extremely large or extremely small heads.

The size or plumpness of seeds of a given variety is correlated with weight per bushel.

NATURAL CROSSING IN FLAX[1]

A. W. HENRY AND CHIH TU[2]

Cultivated flax, *Linum usitatissimum L.*, is generally recognized as being normally self-fertilized. It is so classified for plant breeding purposes in various text-books on the subject (1, 7, 9)[3], but it is pointed out that, owing to the construction and mechanism of the flower, a small amount of cross fertilization might be expected.

LITERATURE REVIEW

Natural hybrids in flax have been reported by several investigators. Cross fertilization is regarded by some as so infrequent as to be negligible and by others as an important factor in affecting the genetic contamination of varieties.

As early as 1910, Howard, *et al* (11) concluded from observations of single plant cultures of linseed that natural crossing undoubtedly occurred in India. Bateson (2) mentioned the possibility of its occurrence in England, but stated that presumably most seed resulted from self-fertilization. Eyre and Smith (6) observe that self-fertilization is not always the case in *L. usitatissimum* in England, and also note the occurrence of natural crossing in *L. humile*. Tammes (14), after growing different varieties in adjacent rows, noticed a small amount of natural crossing and therefore considered isolation or protection necessary in order to preserve genetic purity. Howard, *et al* (12) observed 21 cases of natural crossing from 1916 to 1918.

[1]Contribution from the Department of Plant Pathology, Minnesota Agricultural Experiment Station, St. Paul, Minn. Cooperative investigations between the Minnesota Agricultural Experiment Station and the Offices of Cereal Crops and Diseases and Fiber Plant Investigations of the U. S. Dept. of Agriculture. Published with the approval of the Director as paper No. 799 of the Journal Series of the Minnesota Agricultural Experiment Station. Received for publication August 20, 1928.

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The work was begun by the senior author as a part of a project on the development of rust- and wilt-resistant varieties of seed- and fiber-flaxes. In the spring of 1927, C. V. Kightlinger made the plantings, as the senior author was on leave. The junior author then assumed charge of the work, and completed the experiments.

[3]Reference by number is to "Literature Cited," p. 1192.

Data on the progenies of over 800 selected plants showed that 0.9% were segregating. Fruwirth (7) recognized the possibilities for natural crossing in flax, but was able to obtain but slight evidence of its occurrence after growing distinct types side by side for a number of years. Blaringhem (3) remarks on the danger of cross fertilization and concludes that only constant selection and supervision can give any real guarantee of stability. Graham and Roy (8), from 1916 to 1919, observed 9 cases of natural crossing in 212 pure-line cultures grown in adjacent rows at Nagpur, India. Davin and Searle (5) consider it essential during field selection to protect individual plants by bagging and to keep different families isolated during the early stages of bulking on account of inter-crossing, which they state has been definitely proved.

Bolley (4), after much experience with flax in North Dakota, considers it possible to grow varieties and strains side by side for years "without obtaining any evidences of breaking up of the noticeable characters of flowers, or of other morphological parts, because of fortuitous crossing." He states further that "it probably does not occur in sufficient extent to in any way affect the results in accumulating wilt resistance which we have obtained." Robinson (13) reported that the amount of natural crossing in flax in Michigan varied from zero to 3%, depending on the spacing of the plants and on seasonal conditions. He suggested that the variation in wilt resistance reported by Bolley might be due partly to natural crossing.

OBJECTS OF THE INVESTIGATION

In the course of certain flax breeding work for disease resistance conducted at the University of Minnesota in cooperation with the United States Department of Agriculture, numerous varieties and selections of seed- and fiber-flax were grown in adjacent rows 1 foot apart in order to compare their relative reaction to wilt and rust. Following this procedure, off-type plants or rogues were noticed in several of the cultures. It was thought at first that these probably were mechanical mixtures. Rogues were found, however, in numerous selections with which care had been taken to prevent such mixtures and which had originated from single plants. In several white-flowered selections, for instance, blue-flowered rogues appeared. Seed from several of these was saved and, when sown the following year, the progeny segregated, not only for flower color but also for certain independently inherited characters, such as rust reaction (10). These observations led to the assumption that at least some of the rogues resulted from natural crossing rather than from mechanical mixture or mutation.

It was considered important, therefore, to determine with what frequency natural crossing was occurring under the conditions of the experiments; to ascertain, if possible, the agents affecting it; and to devise feasible methods of preventing it.

AMOUNT OF NATURAL CROSSING AT ST. PAUL, MINN.

In order to obtain data on the amount of natural crossing in the flax nurseries at St. Paul, Minn., white- and blue-flowered varieties were grown in adjacent rows 1 foot apart. Ottawa 770B was chosen as the white-flowered variety for the detection of natural hybrids, as pure material known to be breeding true for flower color was available. Winona was chosen as the blue-flowered variety in the first experiment, but was later replaced by a selection of Argentine flax, the blooming period of which more nearly coincides with that of Ottawa 770B. After growing the white- and blue-flowered varieties side by side for one summer, seed was saved from the white-flowered flax. This was sown, and the resulting plants were examined for flower color. The percentage of blue-flowered plants developing from this seed was noted, the plants were grown to maturity, and their seeds were saved for a progeny test. It was assumed that all plants whose progenies segregated for flower color, blue flowers being dominant to white, were natural hybrids.

As shown in Table 1, 7 blue-flowered rogues out of 400 plants were found in Ottawa 770B after it had grown for one summer between rows of Winona flax 1 foot away. The progenies of five of these plants, as shown in Table 2, segregated for flower color. The other two gave only blue-flowered plants, although their progenies consisted of only nine and five plants, respectively, hardly an adequate test of their breeding behavior. Counting only the plants whose progenies segregated, we have 1.25% natural crossing between these two varieties. Assuming that an equal amount of crossing took place between the white-flowered plants within the row, 2x1.25, or 2.50%, would represent approximately the total amount of natural crossing in this experiment. The natural crossing occurring within the row, of course, would not affect the genetic purity of the variety except in later years when the natural hybrids resulting from crosses with Winona might cross with neighboring plants in the same row. It should be remembered also that the two varieties used in this experiment differed considerably in time of blossoming, Ottawa 770B being almost a week later than Winona. Owing to the habit of prolonged blossoming of flax, however, there was a considerable period during which both varieties were blossoming together.

TABLE 1.—*Percentage of natural crossing in flax as determined by growing white- and blue-flowered varieties in adjacent rows 1 foot apart at University Farm, St. Paul, Minn.*

Year crossing occurred	Varietal combination		Proportions of blue- and white-flowered plants in Ottawa 770B after exposure to natural crossing					
	White-flowered	Blue-flowered	White-flowered		Blue-flowered		Blue-flowered plants whose progenies segregated	
			Number	%	Number	%	Number	%
1924	Ottawa 770B	Winona	393	98.25	7	1.75	5	1.25
1925	Ottawa 770B	Argentine selection	570	97.27	16	2.73	10	1.71

The following year a second similar experiment was begun, using a selection of Argentine flax as the blue-blossomed variety to replace Winona because its blooming period corresponds more closely with that of Ottawa 770B, being only a day or two earlier. The two varieties were grown in adjacent rows during the summer of 1925. During the following winter, 586 plants of Ottawa 770B were grown in the greenhouse from seed obtained from the plants of this variety which had been exposed to natural crossing during the summer. Of these, 570 bred true for white flowers, while 16, or 2.73%, produced blue flowers. These blue-flowered plants were grown to maturity, but

TABLE 2.—*Breeding behavior of the blue-flowered rogues found in Ottawa 770B following its exposure to natural crossing with blue-flowered varieties.*

Plant No.	Number of blue-flowered plants	Number of white-flowered plants	Totals
	Ottawa 770B x Winona		
1	12	5	17
2	16	3	19
3	7	2	9
4	1	1	2
5	2	1	3
6	9	0	9
7	5	0	5
Totals	52	12*	64
	Ottawa 770B x Argentine selection		
1	1	1	2
2	19	7	26
3	6	1	7
4	3	5	8
5	29	7	36
6	0	1	1
7	14	10	24
8	29	7	36
9	28	7	35
10	18	7	25
11	4	0	4
12	6	0	6
13	2	0	2
14	3	0	3
15	0	0	0
16	0	0	0
Totals	162	53†	215

*Expected ratio	37.5 blue	12.5 white	0.24 Dev./P. E.
†Expected ratio	150 blue	50 white	0.73 Dev./P. E.
Artificial cross (observed ratio)	83 blue	19 white	
Winona x Ottawa 770B (expected ratio)	76.5 blue	25.5 white	2.20 Dev./P. E.

the conditions in the greenhouse were not conducive to a good set of seed. Two of the plants failed to produce any seed, while three others yielded only two, four, and six seeds, respectively, and these gave only blue-flowered plants. Ten of the blue-flowered rogues, however, gave segregating progenies. Counting these 10 plants as natural hybrids, then, we would have 1.71% natural crossing between the Argentine selection and Ottawa 770B, or a total of 2x1.71, or 3.42%, assuming again an equal amount of crossing within the row. This is a slightly higher percentage than was obtained in the first experiment, possibly owing to the fact that the two varieties were blossoming together over a longer period. The results of the two experiments are not really comparable as they were not obtained during the same year and it is very probable that climatic conditions affect appreciably the amount of natural crossing.

The breeding behavior of all of the blue-flowered rogues found in the first two experiments is given in Table 2. It will be seen that the totals of the blue- and white-flowered classes of the segregating progenies in both experiments fit an expected 3:1 ratio, blue flowers being dominant. For comparison, the F_2 segregation of an artificial cross between Ottawa 770B and Winona is also given.

AGENTS OF CROSS POLLINATION

Eyre and Smith (6) consider it highly probable that the crossing which does take place in flax results almost entirely from cross pollination brought about by insects. Howard, *et al* (12) note that in India small bees visit the flowers at about ten a.m. and make possible cross fertilization. Fruwirth (7) observed that several species of insects visited flax flowers occasionally, but that bees were the only ones that did so regularly.

Aside from the insects referred to above, the writers have commonly observed thrips in and around flax flowers. These tiny insects can pass through a very small opening and have frequently been seen entering and leaving flowers which had begun to open. They certainly can often gain access to the stigmatic surfaces before self-pollination has taken place, for half-open flowers have often been observed with their anthers still not dehisced. Therefore, it would appear from observational evidence that thrips may be important agents of natural cross pollination of flax.

PREVENTION OF NATURAL CROSSING

Single plants can readily be protected from natural crossing in the field by bagging each plant before any of the flowers open. This involves considerable labor where there are large numbers of plants

to be selfed, since the bagged plants must be supported with stakes in order to prevent lodging. In the writers' experience, better sets of seed have been obtained under cheesecloth than under paper bags. A single thickness of cheesecloth perhaps would not exclude thrips, but possibly this difficulty could be overcome by doubling the cheesecloth or by substituting a finer-meshed cloth.

The next problem is to keep a large number of selfed lines in a state of purity during the early stages of increase and testing. Obviously, there is little use in exercising great care in keeping them pure at first if this care is not maintained later. Apparently, the only solution is to isolate the different selections. The question immediately arises, How far apart must they be placed in order to prevent natural crossing? In order to answer this question, a spacing experiment was made in which blue- and white-flowered varieties, Argentine selection and Ottawa 770B, were grown at different distances from each other. The white-flowered variety was flanked on either side by a row of the blue-flowered variety, the distances betweeen the rows in the different tests varying from 1 to 6 feet. Seed was then saved from the white-flowered variety from eacn of the tests and sown the next year, and the percentage of blue-flowered rogues developing from this seed determined. Data are presented in Table 3 for the first five tests, the plants in the 6-foot test having been harvested by mistake before data were taken. The figures indicate that there was a gradual decrease in amount of natural crossing with increasing distance of the rows apart, except in the 4-foot test which shows a slightly higher percentage than the third. There was, however, still a small amount of crossing when the rows were 5 feet apart. If, therefore, as in this experiment, no other plants intervened between the rows, it would be necessary to space the rows more than 5 feet apart in order to reduce

TABLE 3.—*Effect of distance apart of rows on the amount of natural crossing in flax.*

Distance apart of rows in feet	Total number of plants examined	Number of blue-flowered rogues found	Observed percentage of natural crossing*	Calculated percentage of natural crossing†
1	4,381	55	1.26	1.17
2	3,519	32	0.91	0.93
3	4,380	20	0.46	0.70
4	4,619	25	0.54	0.47
5	3,986	13	0.33	0.23

*Assuming that the blue-flowered rogues were natural hybrids.

†The basis for calculation was on the assumption that the percentage of natural crossing is inversely proportional to the distance between the varieties, $X^2 =$ 0.143543; P will be very large.

the percentage of natural crossing to zero. However, by growing some relatively tall leafy crop, such as oats, between the different flax selections, it is possible that a distance of 5 feet between the rows would be sufficient to prevent natural crossing, but this of course should be determined by experiment. Were the off-type plants in this experiment mutations or mechanical mixtures, one would hardly expect the percentages of such plants to decrease with increasing distances between the rows.

DISCUSSION

Observational evidence indicating that natural crossing of flax was taking place under Minnesota conditions was confirmed by experiment. The percentages of natural crossing demonstrated between varieties grown in rows 1 foot apart, namely, 1.25 and 1.71%, probably err on the low side, if at all, since the varieties used did not blossom at exactly the same time. Furthermore, all of the apparently natural hybrids were not counted, as several of them failed to segregate, although in practically all such cases there was insufficient seed for an adequate progeny test. If, for instance, the six rogues which were not counted in the second experiment actually were natural hybrids, the percentage of natural crossing would be raised from 1.71 to 2.73%.

The amounts of natural crossing found are sufficient, however, to warrant measures being taken to avoid this source of genetic contamination of varieties or selections, for, if allowed to continue over a period of years, serious mixtures would result. Natural crossing will no doubt vary in amount in different years between the same varieties and between different varieties in the same year. In certain cases careful roguing would be fairly effective in maintaining the purity of a selection, as, for instance, that of a white-flowered selection growing among blue-flowered selections. However, where the selections grown in adjacent rows differed in less obvious characters, such as size of flower, earliness, reaction to fungous parasites, or yielding ability, roguing could hardly be depended upon entirely to remove natural hybrids. In such cases other precautions seem necessary. It would seem that the general practice of selfing individual plants, together with the subsequent isolation of their progenies, is advisable where it is desired to maintain flax selections in a pure state. It is realized that this requires much labor and space. In isolating the different selections, however, the space between the different sorts can be utilized to good advantage in increasing other grains. Furthermore, many of the selections can be discarded at an early stage. As

soon as sufficient seed has been obtained, a reserve may be set aside and the rest may be used for carrying out tests in adjacent rows on the basis of which many of the selections can be discarded. Those that prove valuable can be increased from the reserve of pure seed, while that from the test rows can be discarded.

Natural crossing in flax may explain many results difficult to understand otherwise. In connection with disease resistance, for instance, it may explain the diverse results obtained with different selections of the same variety. It may help to explain why varieties of the same name after being grown for a period of years at different stations have shown different degrees of disease resistance, although other factors, such as climatic conditions, soil conditions, and the physiologic specialization of the parasite, may also have an important bearing here. It may help to explain certain apparent cases of accumulation of disease resistance in supposedly pure selections, though Bolley (4) does not consider his results explainable on this basis.

SUMMARY

1. Since off-type plants found in various varieties and selections of flax being tested for rust- and wilt-resistance at University Farm, St. Paul, Minn., seemed to be best explained on the assumption that they were natural hybrids, experiments were made to determine the amount of natural crossing in the flax disease nurseries there.

2. Blue- and white-flowered varieties were grown in adjacent rows 1 foot apart, following which blue-flowered rogues appeared in the white-flowered variety. The progenies of these were tested and those which segregated for flower color were assumed to be natural hybrids.

3. Ottawa 770B was the white-flowered variety used in all experiments. After growing this variety adjacent to Winona, a blue-flowered variety, it was found that 1.25% of natural crossing had occurred. In another test the following year 1.71% natural crossing was demonstrated between Ottawa 770B and Argentine selection. There is reason to believe that these figures may err on the low side. Assuming an equal amount of crossing between white-flowered plants within the row, these figures may be doubled to represent approximately the total amount of natural crossing in these experiments.

4. Observational evidence indicates that thrips may be important agents of natural crossing in flax.

5. By increasing the distance between the rows the percentage of natural crossing was reduced from 1.26 at 1 foot apart to 0.33 at 5 feet apart. It is probable that the amount of natural crossing could be reduced further by growing a relatively tall leafy crop like oats between the rows.

6. Since rouging is an inadequate method of maintaining the purity of flax selections when grown in close proximity to each other and since natural crossing may modify considerably the results obtained, especially in breeding for disease resistance, other measures of preventing cross-pollination, such as the bagging of individual plant selections and the isolation of their progenies, are necessary.

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NATURAL CROSSING IN BARLEY[1]

F. J. STEVENSON[2]

Barley is classed as a naturally self-pollinated plant and, since pollination frequently takes place before the flower opens and while the spike is still in the sheath, the amount of natural crossing is very small. Off-type plants which could be accounted for by natural crossing have been observed by a number of investigators, and it is generally recognized that this phenomenon occurs occasionally. The present study was outlined to test the amount of natural crossing in two-rowed and six-rowed varieties of barley as well as the effect of seasonal variation on natural crossing. Studies of the frequency of natural crossing have been reported by Hayes and Garber[3] and need not be reviewed further.

MATERIALS AND METHODS

The various types of barley used were selected on the basis of their period of maturity, were grown in rod rows 1 foot apart, and were seeded at the same rate as the rod-row tests. White-hulled varieties were grown between two rows of black-hulled of the same species which had a similar habit of growth and approximately the same date of heading. One bearded six-rowed variety was grown between two rows of a hooded six-rowed barley.

The names of the varieties, the type of plant, the differentiating character used in the study, as well as the date of heading for the seasons of 1924, 1925, and 1926 are given in Table 1.

Hanna was grown between two rows of Jet, Consul between two rows of Gatami, Oderbrucker between two rows of Lion, and Manchuria, Minn. No. 184, between two rows of Nepal. The varieties grown side by side were selected because of their similarity in type, growth habit, and date heading.

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[2]Assistant Professor of Plant Genetics and Assistant Plant Geneticist. This study is one of several which have been conducted at University Farm, for the purpose of learning the normal mode of pollination of crop plants. The project with barley was outlined in 1924 and was turned over to the writer in the fall of 1925. The writer wishes to express his appreciation to Dr. H. K. Hayes for the opportunity of completing this study and for valuable suggestions made during the progress of the work.

[3]HAYES, H. K., and GARBER, R. J. Breeding Crop Plants. New York: McGraw-Hill Company. 1927.

TABLE 1.—*Name of variety, type of plant, differentiating characters used, and date heading for the seasons of 1924, 1925, and 1926.*

Variety	Type	Character	Date heading 1924	1925	1926
Jet	two-rowed	black	July 1	June 15	June 20
Hanna	two-rowed	white	July 2	June 22	June 23
Gatami	six-rowed	black	June 26	June 12	June 15
Consul	six-rowed	white	June 27	June 12	June 12
Lion	six-rowed	black	June 29	June 14	June 15
Oderbrucker	six-rowed	white	June 29	June 22	June 19
Nepal	six-rowed	hooded	June 30	June 22	June 22
Manchuria, Minn. No. 184	six-rowed	awned	June 29	June 22	June 20

The rows of each of the varieties Hanna, Consul, Oderbrucker, and Manchuria, Minn. No. 184, were harvested in bulk. The following season 4,000 to 10,000 seeds obtained from each of these rows were planted at the rate of 75 seeds to an 18-foot row, the seeds being spaced about 3 inches apart in the row. A count was made at harvest time of the total number of plants and the off-type plants, either black or hooded, which were observed.

The black or hooded plants were harvested individually and tested the following season to determine whether or not they were hybrids. It required, therefore, three growing seasons to test the amount of natural crossing which occurred between two varieties in any one year. The first year the varieties were grown in adjacent rows; the next, a large number of plants were grown from seed saved from the white-hulled rows or bearded rows, as the case might be; and the third year, the progeny of off-type black-hulled or hooded plants which occurred were tested to determine their breeding behavior. The test was continued for three seasons to determine the amount of seasonal variation.

RESULTS

The total number of plants of each variety grown, the hybrids obtained, and the percentages of natural crosses observed in 1924, 1925, and 1926 are given in Table 2.

No hybrids were obtained between the two two-rowed varieties, Hanna and Jet. A small amount of natural crossing, 0.04% for 1924, 0.12% for 1925, and 0.15% for 1926, was found in Consul, one of the six-rowed varieties. One hybrid occurred between Manchuria, Minn. No. 184, and one of the black forms in 1925, but no hybrids were obtained between Manchuria, Minn. No. 184, and the hooded variety, Nepal. Oderbrucker showed no natural crossing in any of the trials.

TABLE 2.—*The number and percentage of natural crosses observed in barley varieties in 1924, 1925, and 1926.*

Variety	1924				1925				1926			
	White	Black	Hybrid	Natural cross %	White	Black	Hybrid	Natural cross %	White	Black	Hybrid	Natural cross %
Hanna	3,543	0	0	0	2,264	0	0	0	4,039	0	0	0
Consul	2,878	1	1	0.04	1,600	2	2	0.12	2,012	3	3	0.15
Oderbrucker	3,443	0	0	0	2,143	4	0	0	3,869	0	0	0
Manchuria, Minn. No. 184	3,937	0	0	0	2,089	1	1	0.05	3,998	0	0	0

The data presented give the number of natural crosses which occurred between different forms and which could be differentiated under the plan outlined. It is probable that cross-pollination took place in the opposite direction and it is probable, also, that off-pollination between different plants in the same row may have occurred. The data presented here are sufficient to show that a small amount of natural crossing probably takes place each year at University Farm in some of the six-rowed forms of barley.

No off-types were observed in Hanna, a two-rowed variety, or Oderbrucker, a six-rowed form, and only a single natural cross occurred in Manchuria, Minn. No. 184, out of a total of 10,024 plants, while Consul gave some natural crosses in each of the three years of the trial.

The variation due to seasonal differences was not very great. There is enough natural crossing in a variety like Consul to produce in time many off-type plants if it is grown close to other types of barley. In this case, a systematic roguing of such varieties must be resorted to if a uniform product is to be maintained by the plant breeder. If a careful genetic study is to be made of the progeny of hybrids between two varieties, enough natural crossing has been demonstrated by this experiment to warrant the testing of the breeding behavior of the exact plants which were used as parents in making the crosses. There is not enough, however, to necessitate bagging or isolation of the hybrids or their progeny since the few aberrant types which might be found in these, due to natural crossing, would not change the results materially.

SUMMARY

1. Three white-hulled varieties of barley were grown between black-hulled varieties of the same type, habit of growth, and date of heading for the three years 1924, 1925, and 1926. One of these varieties, Hanna, was two-rowed and two others, Consul and Oderbrucker, were six-rowed. Manchuria, Minn. No. 184, an awned six-rowed variety, was grown between two rows of Nepal, a hooded six-rowed sort.

2. Natural crossing varied with the variety. No hybrids were found in Hanna or Oderbrucker, but small amounts of natural crossing, 0.04% for 1924, 0.12% for 1925, and 0.15% for 1926, were found in Consul, while 1 natural cross out of a total of over 10,000 plants was found between Manchuria, Minn. No. 184, and one of the black types. No natural crossing was observed between Manchuria, Minn. No. 184, an awned variety, and Nepal, a hooded variety.

3. Seasonal differences did not have as great an effect as varietal differences.

EVIDENCE AND OBSERVATIONS ON ESTABLISHING SWEET CLOVER IN PERMANENT BLUEGRASS PASTURES[1]

L. F. GRABER[2]

In 1927, the writer[3] reported some results covering three years of effort in establishing sweet clover successfully in permanent bluegrass pastures where plowing was not practical or desirable. Among the many essentials for the attainment of this type of pasture improvement, it was shown that the removal of accumulations of old grass by burning or otherwise was necessary in order "to permit the (sweet clover) seed to come in contact with the soil." The writer is now of the opinion that where burning is not feasible, cultivation of pasture lands by means of a disk or spring tooth harrow will be a requirement for such soil contact and for successful seeding on dense sods. On fertile soils with very dense sods, both burning and cultivation may be advisable.

The present treatise has been prepared to emphasize the importance of including this phase of the establishment of sweet clover and other legumes in bluegrass pastures, as a part of the experimental procedure which will be needed to determine the possibilities of this plan of pasture improvement.

SEED SHOULD MAKE SOIL CONTACT

The necessity for the removal of large accumulations of old grass is not only shown by data previously reported, but will be amplified by experimental evidence from seedings made in 1927 and 1928. In some trials where burning was not possible due to moisture and a lack of sufficient old grass, certain conditions have indicated that the absence of cultivation was the factor which limited success on dense sods. A brief description of these and other field trials in the grazing regions of southwestern Wisconsin will suffice to emphasize the importance of soil contacts for legume seeds sown in permanent bluegrass pastures.

[1]Contribution from the Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wis. Published with approval of the Director. Received for publication August 15, 1928.

[2]Professor of Agronomy.

[3]GRABER, L. F. Improvement of permanent bluegrass pastures with sweet clover. Jour. Amer. Soc. Agron., 19:994–1006. 1927.

FIELD TRIAL NO. 1

Sweet clover was seeded on an area of 3 acres of a 20-year-old dense pasture sod which was fenced off from the balance of a large pasture in southwestern Wisconsin. The soil was limed heavily just prior to sowing common white biennial sweet clover (*Melilotus alba*) on March 24, 1928, at the rate of 30 pounds of inoculated seed per acre. A small accumulation of old grass was not burned off prior to seeding, but on a large part of this 3-acre plat the sod had been completely eaten off from the surface of the soil and killed by white grubs in 1927. Much of this dense sod was turned over by hogs in the fall of that year. In August, 1928, the sweet clover was an excellent stand wherever the sod was "rooted up" so that the seeds and the lime came in contact with the soil at the time of application. In spots where the sod was dead but had not been disturbed, the sweet clover failed to become established. It failed in all those places where the sod was alive and thick and with no apparent grub injury. It failed in spots where a layer of ground limestone about an inch in thickness covered an otherwise bare soil. It succeeded on bare soil at and along the edge of these remains of piles of limestone which were not completely spread.

In other words, the only places in this 3-acre tract where sweet clover succeeded was where the seed made contact with the soil. On the ground limestone, on the dead sod, and on the live sod with dense accumulations of undecomposed organic matter from dead leaves and from roots and rhizomes of the grasses, the scarified sweet clover seeds sprouted but the moisture-retaining capacity of this medium of germination was not sufficient to warrant the establishment of seedling plants. It is believed that the sprouted seeds withered and died except in those places where they made soil contacts at or shortly after the time of seeding on frozen ground. Here the roots developed in a medium of loam soil sufficiently retentive of moisture and with other essentials for plant growth to result in the establishment of strong seedling plants of sweet clover.

FIELD TRIAL NO. 2

On a fenced tenth-acre plat of a 30-year-old bluegrass sod which had been almost completely eaten off by grubs in 1927, the writer applied lime in August, 1927, and seeded sweet clover on March 24, 1928. There was no grazing on this plat in 1927 and 1928. The sweet clover was only successful where the dead sod had been removed by the writer in the fall of 1927, thus permitting the seeds to come in contact with the soil. The unremoved dead sod was not sufficiently retentive of moisture to maintain the growth of the sprouted seeds.

FIELD TRIAL NO. 3

This trial was conducted on 4 acres of old grass land, low in fertility and productivity. The pasture was not burned or cultivated. The plat was fenced to eliminate grazing during 1928. Finely ground limestone at the rate of 3 tons per acre and 20% superphosphate (acid phosphate) at the rate of 400 pounds per acre were applied in February, 1928. On March 20, 1928, 30 pounds per acre of inoculated common white biennial sweet clover were sown on frozen ground. Except for two spots where the soil was bare, not a plant of sweet clover has been found during the summer of 1928.

It is planned to reseed this infertile pasture with sweet clover and other legumes on frozen ground in the spring of 1929, but before seed is applied a definite part of the plat will be disked, a definite part will be burned, a definite part will receive both burning and cultivation, and the remainder will receive no treatment. Had such procedure been followed before seeding in 1928, the status of our present knowledge on this phase of seeding pastures may have been greatly enhanced. The fact, however, that in 1929 the lime and phosphate will have been applied on this plat a year in advance will give considerable assurance that the unalterable requirements of legumes in this respect will be satisfied. Since applications of ground limestone on plowed land are most effective after they have been incorporated in the soil for at least a year, it would appear that when lime and other mineral fertilizers are applied as a top dressing in a bluegrass pasture so that rainfall must be depended upon largely to carry this material into the soil application a year in advance of the time of seeding sweet clover and other legumes may be desirable and in many cases necessary.

SUCCESS WITH CULTIVATION

FIELD TRIAL NO. 4

On another dense, but fertile, bluegrass sod in southwestern Wisconsin 4 acres were fenced and seeded with inoculated common biennial white sweet clover at the rate of 30 pounds per acre, during the period of alternate freezing and thawing in the spring of 1928. These 4 acres were limed at the rate of 2 tons per acre in 1926. The grass had been grazed closely in 1927 so that (as is often the case) there was no opportunity for burning off old grass prior to seeding. Just before sowing the sweet clover seed the sod was disked thoroughly, the frost having thawed sufficiently for this purpose. After seeding, the pasture was dragged with a harrow, At present the grass is not only thick, but in it the sweet clover is uniformly excellent in stand and growth.

CULTIVATION OR BURNING

The successes which have been attained for the past four years on the Experiment Station farm at Madison, Wisconsin, without cultivation but with burning and other means of removing old grass, were not accomplished on dense sod. Here the sod was thin so that much of the soil was exposed and not covered by a heavy network of roots, rhizomes, and other vegetative material. Burning off large accumulations of old grass under such conditions not only retarded the growth of bluegrass but helped to destroy enough of the undecomposed organic matter in the sod to permit the sweet clover seeds to make a good contact with the soil.

Even burning small accumulations of only 418 pounds an acre of dry old grass on such sod in 1928 resulted in 14 seedling plants of sweet clover per square foot as compared with only 9 in the unburned sod. The sweet clover was seeded at the rate of 30 pounds per acre on frozen ground during the period of alternate freezing and thawing on March 24, 1928. The burning was done the previous day and the determinations on thickness of stand were made August 8, 1928.

In another similar plat on this same area of bluegrass, Dutch clover (*Trifolium repens*) was sown at the same time but at the rate of 15 pounds per acre on burned and unburned bluegrass sod. While no plant counts were made, the stand of Dutch clover on August 8, 1928, was satisfactory in both plats but very much thicker where the small accumulations of old grass had been burned off prior to seeding.

In those places where, due to previous heavy grazing, the amount of old grass is not sufficient for satisfactory burning, soil contacts for seeds can be provided by thorough disking or similar cultivation with a spring tooth harrow. Both cultural procedures—burning and cultivation—may be desirable in the event of very dense sods but neither may be required on very thin sods where the soil is sufficiently exposed and where accumulations of old grass have been eliminated by close grazing, burning, or mowing.

Whatever the method may be, the objective is to provide a favorable medium for germination and growth of legume seeds sufficiently retentive of moisture under the existing climatic conditions to warrant the establishment of the seedling plants in competition with perennial grasses.

Even in the absence of sufficient data to substantiate definite recommendations, the writer predicts that this feature of establishing legumes in old pastures will prove of equal practical importance to those known essentials, such as soils high in available lime, phosphate, potash, and other mineral nutrients; the avoidance of heavy, if not all, grazing the first year of seeding; inoculation of the

seed or soil before sowing; and seeding so as to provide a period of alternate freezing and thawing which aids in covering the seed.

DIFFICULTIES ON LIGHT SOIL

In many places the establishment of sweet clover and other legumes in permanent pastures, which have been burned over or cultivated, or both, will be made very difficult where, after seeding, the moisture content of the soil is greatly limited either by a lack of rainfall or by virtue of a physical state of the soil such as exists in light sandy types that are not retentive of moisture. Where both drought and a failure of the soil to retain moisture operate, there is little opportunity for sweet clover and much less for other legume seedlings to develop in competition with the existing grasses. It is also very doubtful if, on sandy soils, alternate freezing and thawing will provide for proper covering of the seed. Cultivation after seeding may be necessary for this purpose on light soil pastures.

RATES OF SEEDING

On a Miami silt loam on the Experiment Station Farm at Madison, Wisconsin, scarified and unhulled sweet clover seeds were sown March 17, 1927, at 10-, 20-, and 30-pound rates per acre on bluegrass sod which had been established for a period of 12 years. The soil was not covered with a heavy sod of roots and rhizomes but a large accumulation of old grass was present. This old grass was removed from one part of the plat on November 5, 1926, by mowing and raking and from another part of the plat by burning on March 17, 1927. The amount of such old grass removed by cutting was at the rate of 2,261 pounds of dry hay per acre and by burning 2,005 pounds per acre. The seed was sown in long strips across and at right angles to areas where the grass had and had not been removed.

While no cultivation was practiced, it should be emphasized that this bluegrass sod was very favorable for the establishment of sweet clover. The sod was neither thick nor dense. The grass was not vigorous because the soil was deficient in nitrogen. There was a natural content of available mineral nutrients ample to take care of ordinary sweet clover requirements. Inoculation was provided. Under such conditions the establishment of soil contacts for the sweet clover seeds by the removal of the old grass and the seeding of sweet clover during the period of alternate freezing and thawing was all that proved necessary in these respects for success.

The scarified common biennial white sweet clover seed which was sown germinated 94% and in addition 3% of the seeds were hard or impermeable. The unhulled seed (which later proved to be of the Grundy County strain of biennial white sweet clover instead of the common white) gave an immediate germination of only 3% with 97% hard seeds. On September 24, 1927, the thickness of stand was determined by counts on areas of 9 square feet. The results are given in Table 1.

TABLE 1.—*A comparison of rates of seeding scarified and unhulled sweet clover seed on a 12-year-old bluegrass sod with special reference to thickness of stand where the old grass was and was not removed by burning and by cutting prior to seeding on March 17, 1927.*

Treatment of plats of bluegrass sod before seeding sweet clover	Kind of seed sown	Pounds of seed sown per acre	Number of plants on 9 square feet, Sept. 24, 1927
Accumulation of old grass from previous years burned off on March 17, 1927, just prior to seeding.	Unhulled	10	21
		20	23
		30	37
	Scarified	10	54
		20	67
		30	126
Accumulation of old grass of previous years was cut with a field mower and raked off this plat on Nov. 5, 1926. Sweet clover seed sown March 17, 1927.	Unhulled	10	8
		20	48
		30	33
	Scarified	10	12
		20	44
		30	84
Accumulation of old grass not removed. Sweet clover seed sown March 17, 1927.	Unhulled	10	4
		20	2
		30	7
	Scarified	10	8
		20	5
		30	9

As was true in trials previously reported, the stands and growths of sweet clover were unsatisfactory where accumulations of old grass were not removed. Burning resulted in better stands than removals by cutting and raking. It is believed that in addition to depressing the subsequent growth of bluegrass, burning provided closer soil contacts for the seed. The unhulled seed was unsatisfactory for spring sowing. It resulted in much thinner stands of sweet clover than the seeds which had been scarified. In all cases but one, the 30-pound rate of seeding gave the thickest and most uniform stands. This appears logical. In seeding legumes, such as sweet clover, in permanent grass sod heavier rates of seeding will be required than would be necessary on a carefully prepared seedbed. While such limiting factors of growth in legumes as the absence of lime, phosphorus, or

potash cannot be overcome by sowing more seed, heavier rates of seeding will tend to offset the heavier losses of seedling plants which may well be expected where a good seedbed is not provided.

While no specific rate of sowing sweet clover in bluegrass can be offered which will apply to all conditions, it is believed that for the wide range in the time of seeding during the spring period of alternate freezing and thawing and for a wide range of soil conditions, heavy rates will give the most uniform and most desirable thickness of stand.

SWEET CLOVER STIMULATES PASTURE GRASSES

While it is true that to establish sweet clover in permanent pastures will often require cultivation or burning, or both, which will depress the growth of the grasses, such temporary depression has been insignificant in comparison with the extended benefits which obtain in subsequent soil improvement from the growth of sweet clover in bluegrass. As reported previously,[4] the growth of sweet clover in a burned bluegrass pasture during 1925 and 1926 trebled the yields of bluegrass in 1927 as compared with adjacent bluegrass in which sweet clover had not been grown. In 1928 the soil improvement was still pronounced. At maturity the bluegrass in which sweet clover had grown in 1925 and 1926 yielded at the rate of 5,066 pounds of oven-dried hay per acre as compared with 2,722 pounds per acre where no sweet clover had been grown.

The growth of sweet clover in another plat during 1926 and 1927 resulted in a yield of oven-dried bluegrass hay of 4,840 pounds per acre in 1928 as compared with 3,727 pounds per acre of adjacent bluegrass where no sweet clover was previously grown. The degree of response in the way of soil improvement by abundant growths of sweet clover is much dependent upon the degree of deficiency in the nitrogen content of the soil. Most poor pastures are highly deficient in nitrogen. It is on the poor pastures where the establishment of sweet clover has its most significant application.

The benefits in soil improvement where sweet clover can be successfully established in poor pasture lands will tend to extend the practice of liming and also of fertilization of pastures with mineral fertilizers where such treatments are needed.

AVOIDANCE OF GRAZING FOR ONE YEAR JUSTIFIED

Results obtained in 1928 are in accord with those reported in 1927 in which the elimination of grazing during the first year of seeding sweet clover in bluegrass was justified by the increase in the grazing capacity during the second year's growth of the sweet clover in combination with bluegrass.

[4]*Loc. cit.*

In 1926 and in 1927 the second year's growth of sweet clover and bluegrass combined was more than double the yields of dry matter obtained with bluegrass alone. Sweet clover successfully established in bluegrass in 1927 gave a yield of 3,521 pounds per acre of oven-dried hay before blossoming in 1928, and in addition, the growth of bluegrass in the dense sweet clover amounted to 1,602 pounds per acre, making a total of 5,123 pounds. Mature bluegrass growing alone in an adjacent area yielded at the same time only 2,183 pounds of dry hay per acre.

The avoidance of such grazing during the seedling year in the growth of sweet clover as may be necessary to give the sweet clover plants an opportunity to establish their roots and to build up a reserve supply of organic foods has been amply justified by the increased yields of bluegrass and sweet clover combined which were obtained the following season. Particularly is this true on poor pasture land where the productivity is so limited that little is sacrificed by eliminating all grazing for one year.

SUMMARY

In addition to those known requirements of success in establishing sweet clover in permanent bluegrass pastures, such as a soil abundant in all available mineral nutrients, proper inoculation, and the avoidance of heavy grazing during the first year of seeding, emphasis is given to the establishment of proper soil contacts at the time of sowing legume seeds. This may be accomplished in some cases by burning off accumulations of old grass prior to seeding legumes in a pasture; but where such burning is not feasible and especially where the grass sod is thick and dense, cultivation by means of a disk or spring tooth harrow is suggested as a part of the experimental procedure to determine the possibilities of pasture improvement by seeding with legumes. Such surface scarification provides not only for soil contacts and covering of seed, but also for a more rapid incorporation of applied lime and mineral fertilizers into the soil and a more dependable source of moisture for growing legume seedlings than that of a dense unbroken sod. It provides a seedbed without permanently injuring the grass and without serious danger of erosion on hilly lands. It provides a temporary retardment of the growth of the grasses. All these factors help the juvenile legume plants to become established in pastures.

For seeding during the spring period of alternate freezing and thawing, scarified sweet clover seed was much superior to unhulled seed; but 30 pounds of scarified seed per acre gave thicker and more uniform stands than 20- and 10-pound rates of seeding.

The yields of grasses have been greatly increased following the biennial period of growth of common white sweet clover in permanent pastures. This improvement, together with the increased yields of the second year's growth of sweet clover in combination with bluegrass, has given ample justification for the elimination of such grazing as may be necessary to warrant the establishment of a thick stand of seedling sweet clover plants in a bluegrass sod. Such benefits also promise to extend the practices of liming and of mineral fertilization of pasture lands where needed.

EFFECT OF WIND ON PLANT GROWTH[1]

H. H. FINNELL[2]

Statistical analyses of field data of factors affecting crop yields at the Panhandle Agricultural Experiment Station, Goodwell, Oklahoma, seem to indicate a greater damaging effect of high winds upon plant growth than would be expected by reason of increased transpiration alone. To secure further information of the importance of physical damage from wind, simple pot tests using wind as the sole variable factor were devised and preliminary resuts are reported here. Attention was given to providing comparable conditions of temperature, humidity, light, and moisture.

METHODS

Marigolds were used as representative of tender-foliage plants. Two pairs of plants were selected from a large number which had been transplanted to 6-inch clay pots, equally filled from a single mixture of greenhouse soil. The stage of growth shown in Fig. 1 was reached before a division of the pots was made. Optimum moisture was then determined by saturation, drainage, and 24-hour greenhouse exposure, repeated. Numbers A1 and B1 were placed in front of a 12-inch electric fan, at a distance of 80 cm, where they remained continuously for 60 days exposed to a wind velocity of approximately 15 miles per hour. Numbers A2 and B2 were placed in the same room with the wind-exposed pots about the same distance behind the fan where the air was comparatively still. All pots were brought back to optimum moisture every 24 hours, the water usage and height of plants being recorded daily. Wind velocity was determined by a Robinson cup wind gage set up in place of the pots.

Table 1 presents in condensed form the data of growth, water requirement, and yield. Table 2 gives the air and light conditions surrounding the experiment by the same periods represented in Table 1 under the heading "Average Daily Water Used."

DISCUSSION

The difference in rate of growth between exposed and check plants was measurable after the first 24 hours. Apparently there was considerable repair of tissues required as well as an actual loss of leaves as indicated by the curled and withered conditions noted in Figs. 2, 3, and 4. Careful inspection was made to determine the

[1]Contribution from the Panhandle Agricultural Experiment Station, Goodwell, Oklahoma. Received for publication August 14, 1928.

[2]Director and Agronomist.

FIG. 1.—Plants at beginning of wind test.

presence of disease or other unusual condition but none were found. At first the wind-exposed pots used considerably more water daily, but near the 30th day the check plants had so far outgrown those exposed to the wind that they were using approximately the same amount of water and continued to do so to the end of the experiment.

The percentage of dry matter was consistently higher in all parts of the check plants when harvested. This difference is assumed to

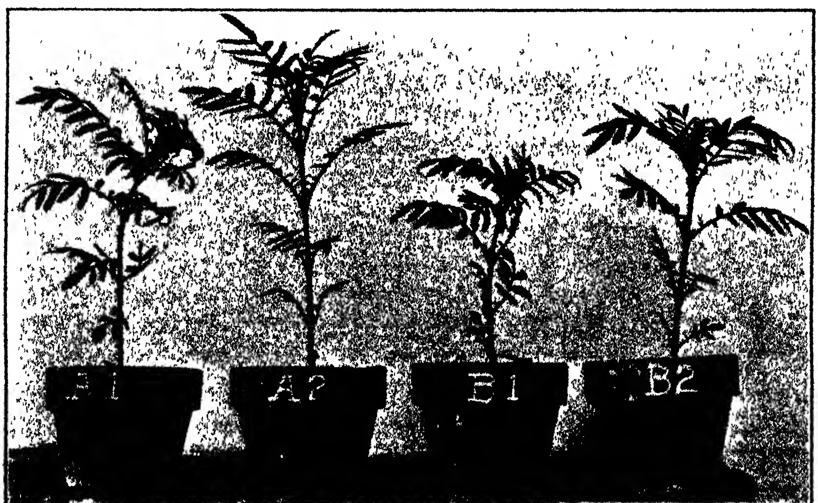

FIG. 2.—Plants six days after start of test.

TABLE 1.—*Effect of wind on growth of pot marigold.*

	Wind-exposed plants*			Check plants		
	A1	B1	Average	A2	B2	Average
Initial height, cm	24.0	16.0	20.0	24.5	18.0	21.2
Increased height:						
1 to 10 days	5.5	7.5	6.5	13.0	11.0	12.0
11 to 20 days	6.5	8.0	7.2	13.5	12.0	12.7
21 to 30 days	15.0	18.0	16.5	27.5	21.5	24.5
31 to 40 days	14.5	16.5	15.5	7.0	19.0	13.0
41 to 60 days	18.5	26.0	22.2	16.5	10.5	13.5
Final height	84.0	92.0	88.0	102.0	92.0	97.0
Average daily water used, cc:						
1 to 10 days	233.0	226.0	229.5	194.3	139.6	166.95
11 to 20 days	185.8	183.0	184.4	170.7	137.0	153.80
21 to 30 days	271.9	285.8	278.8	275.4	221.6	248.50
31 to 40 days	186.3	197.7	192.0	211.6	178.7	195.10
41 to 50 days	221.3	248.6	239.9	257.6	205.5	231.50
51 to 60 days	228.9	259.9	244.4	256.0	233.5	244.70
Average daily water used per pot, cc	221.2	233.5	227.3	227.6	192.8	210.2
Water used per gram dry matter, cc	2,765	1,668	2,216	1,198	803	1,000
Green weights cut, grams						
Stem	16.1	21.8	18.9	22.3	31.7	26.9
Leaves	8.6	18.4	13.5	11.0	23.3	17.2
Flowers	2.9	3.5	3.2	7.8	9.6	8.7
Total green weight	27.6	43.7	35.6	41.1	65.5	52.8
Dry matter, green basis, %						
Stem	14.9	20.1	17.5	26.9	22.3	24.6
Leaves	23.2	18.4	20.8	28.1	21.4	24.7
Flowers	13.7	17.1	15.4	29.4	23.9	26.6
Whole plant	17.4	19.2	18.3	27.7	21.9	24.8
Dry matter in grams						
Stems	2.4	4.4	3.4	6.0	7.1	6.5
Leaves	2.0	3.4	2.7	3.1	5.0	4.0
Flowers	0.4	0.6	0.5	2.3	2.3	2.3
Total:	4.8	8.4	6.6	11.4	14.4	12.8
Number blooms at harvest	1.0	1.0	1.0	3.0	2.0	2.5
Number buds at harvest	4.0	3.0	3.5	3.0	3.0	3.0
Number secondary branches	5.0	5.0	5.0	4.0	3.0	3.5

*Wind velocity 15.15 miles per hour.

be a normal variation in keeping with the stage of maturity reached in the two pairs of plants rather than due to any morphological modification from the effects of wind. Apparently, exposure to wind had the effect of postponing maturity about ten days.

It seems pertinent to offer the following criticisms. Evaporation from pot and soil surface was not controlled so that the values repre-

senting water used per gram dry matter do not represent plant usage. After the plants reached a height of 50 cm. the entire area of the wind-exposed plants was not subject to the same velocity. In fact it was noticeable that after the growing parts reached above the main air draft they showed remarkable relief from the wind and resumed normal growth. Plants were selected on the basis of apparent equality in foliage area and total height, but measurements were made from crown to youngest node of center stem. These measurements were discontinued when the secondary branches and flower buds appeared. A sufficient number of replications was not made to secure a reasonable degree of accuracy in results. Since this was, at the outset, intended to be only a preliminary trial of technic preparatory to experiments with local crop plants, the small number of pots was carried through. However, the results were apparently of such significance as to warrent a brief report.

TABLE 2.—*Air and light conditions.*

Period	Mean temperature °F	Cloudiness %	Relative humidity %
1 to 10 days	58.6	50	68.2
11 to 20 days	59.4	50	58.4
21 to 30 days	70.1	45	66.4
31 to 40 days	64.6	45	72.1
41 to 50 days	70.3	30	67.4
51 to 60 days	74.2	50	60.5

FIG. 3.—Plants 12 days after start of test.

FIG. 4.—Plants 44 days after start of test.

SUMMARY

1. A portion of the tender foliage was actually destroyed by wind whipping.

2. Deformation of the main stem was marked in early growth stages.

3. Rate of growth as measured by height of plant was immediately reduced.

4. Time of maturity was increased by wind about 10 days in a 60-day growing period.

5. Yield of dry matter was reduced 48.8% by wind.

6. Total water requirements per pot did not vary significantly.

7. Water requirements per unit of dry matter produced were approximately doubled by exposure of plant and pot to wind.

8. The number of secondary branches formed was apparently increased 42.8% by wind.

FERTILIZER AND LEGUME EXPERIMENTS FOLLOWING SORGHUMS[1]

JOHN P. CONRAD[2]

INTRODUCTION

Until recently two theories had been seriously considered to explain the injury that sorghums caused to crops following them. According to one, the sorghum crops take so much of the essential elements from the soil that there is an insufficient amount left in available form to meet the normal needs of plant growth. According to the other, toxins or "toxic bodies" develop in the soil during the decomposition of the sorghum stubble, which injure the crop plants following. Sewell (8)[3] lists other causes which have been suggested.

Recently, the writer (3) suggested that another theory worked out in connection with cereal straws was more applicable to his observations and those of others in the literature than the two formerly considered. According to this theory, the injury is due to competition for available essential elements or ions between the crop plants following the sorghum crop, on the one hand, and the micro-organisms of the soil, on the other hand. The competition of the micro-organisms is made much more effective than occurs under ordinary soil conditions because of the high amount of sugars and possibly other easily decomposable carbonaceous compounds in the sorghums. These furnish the organisms a source of energy causing them to multiply greatly in numbers. In so doing they would draw from the soil solution ions essential for growth, thereby cutting down the amount left that the crop plants could draw upon. Though no rigorous proof of this theory as the only theory applicable has been established, enough evidence is available to show that it accounts for a considerable amount of the injury.

The literature has been previously reviewed (3). Since that time, however, the work of Wilson and Wilson (11) has appeared which adds still more evidence to support the theory considered by the writer as applicable to the sorghum injury. They give additional evidence that sorghum roots depress nitrates in the soil to a greater extent or for a longer time than do corn roots. Even when the amount of corn roots was increased relative to the sorghum roots so

[1]Contribution from the Division of Agronomy, University of California, Davis, California. Received for publication October 1, 1928.

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[3]Reference by number is to "Literature Cited," p. 1233.

as to given an equal addition of water-soluble organic matter in both, still sorghum roots depressed nitrification to a greater extent. Higher bacterial counts were secured at the start from incubation of soil containing sorghum roots than from soil containing corn. Greater amounts of carbon dioxide were given off during the first part of an incubation experiment from sorghum roots than from corn roots. All of these phenomena tend to support the theory of sorghum injury recently suggested as against the two theories previously postulated.

Under field conditions, in most of the West at least, nitrogen in available form is considered the element which becomes lacking first. It would naturally follow then from this theory of sorghum injury that crops suffering because they follow sorghums probably are stunted from lack of available nitrogen. Applications of fertilizers carrying readily available nitrogen should then increase a non-leguminous crop, the increases should be greater the greater the rate of nitrogen application per unit of area, and inoculated legumes should be harmed very little if any by this crop sequence. This paper gives some data on these points both from field experiments and from pot trials.

FERTILIZER EXPERIMENTS

Two one-tenth acre plats which had been in a fairly uniform stand of White Durra were selected in the fall of 1927 for the fertilizer trials at Davis. After the removal of the stalks, the plats were disked only. Vaughn barley was carefully sown on December 7, 1927, with a 6-foot drill. There were 6 drill widths per plat, or 12 altogether, each 121 feet long.

Each drill width was divided lengthwise into five sub-plats each 20 feet long by 6 feet wide with 5-foot alleys in between lengthwise. These alleys gave access to each sub-plat without walking over the others. Commercial nitrate of soda was dissolved in a barrel and distributed on the sub-plats as equally as possible with a sprinkling can. Rates of application were 100 pounds, 200 pounds, none, and 400 pounds in the order given. Each rate of fertilizer was applied on each of the three dates, *viz.*, December 17, 1927, just before the grain emerged from the ground which was as close to planting time as the work could be done; February 27, 1928, when the grain was 10 to 12 inches high; and on March 29, 1928, when the grain was in the boot. This gave five replications for each treatment.

Unfortunately, the yields from the sub-plats around the edge of the larger plats and at the ends had to be discarded. The winter rains falling upon the irrigation levees which are kept cultivated evidently leached out the nitrates which ran into the sub-plats around the

edges. The remaining sub-plats, however, gave duplicate results for each of these treatments uncontaminated by leachings from the irrigation levees. The yields were secured by harvesting two adjacent drill rows for 20 feet down the center of the sub-plat or the yield from 20 square feet. This is similar to the method used by the plant breeders of the station for testing varieties. The bundles were weighed in grams, the grain threshed out with a nursery thresher and weighed in grams.[4] Table 1 gives the height of crop, yield of total crop, and yield of threshed grain from this test.

The growth changed from a light or yellowish green color to a dark green soon after the fertilizer was applied. This deep color persisted for several weeks after the application, gradually fading in intensity. There was little difference in the time of maturity of the various sub-

TABLE 1.—*Effect of nitrate of soda applications on the height, yield of total crop, and yield of threshed grain with Vaughn barley following White Durra, Davis, 1928.*

Number of sub-plats	Pounds nitrate of soda per acre	Date of application	Height, inches	Total yield per acre, pounds	Yield threshed grain in pounds per acre
6	None		29.5	2,745	1,225
2	100	Dec. 17, 1927	38.5	4,650	2,070
2	100	Feb. 27, 1928	36.5	4,760	2,055
2	100	Mar. 29, 1928	34	4,570	1,965
2	200	Dec. 17, 1927	39.5	5,640	2,180
2	200	Feb. 27, 1928	36.5	5,750	2,550
2	200	Mar. 29, 1928	30	5,510	2,330
2	400	Dec. 17, 1928	42.5	6,990	2,670
2	400	Feb. 27, 1928	41	7,470	2,850
2	400	Mar. 29, 1928	31	5,990	2,640

[4]During 1927, the yields of total crop from separate drill rows of the preliminary trials were harvested separately and are listed below with yields given in grams per 20-foot row every 6 inches.

Rate of application of nitrate of soda per acre

200 pounds	400 pounds	600 pounds
545	590	701
465	685	760
605	555	688
380	507	785
500	500	619
465	645	790

From these figures can be seen the amount of variation that is apt to occur by harvesting drill rows as a sample of the yield of the sub-plat where the fertilizer dissolved in water has been distributed with a sprinkling can. No work was done with the 1928 crop on this point as the average of the different replications would ordinarily take care of this factor of error.

plats except that those receiving the heavy applications on December 17, 1927, and February 27, 1928, matured slightly earlier than the unfertilized check plats alongside. This can be explained on the basis of the larger use of moisture by the heavier crop inducing slightly earlier ripening. At the time of the last application of fertilizer the crop was "in the boot." The added growth was made by new tillers

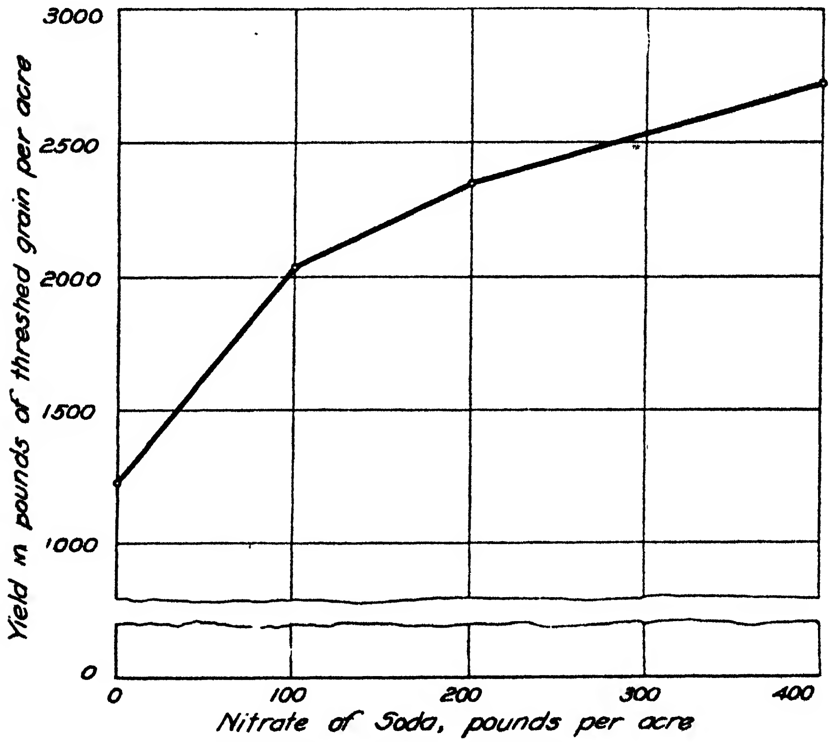

FIG. 1.—Effect of varying the rate of application of nitrate of soda on the yield of Vaughn barley following White Durra, Davis, Calif., 1928.

arising from the crown. The heads in the boot went ahead to maturity at about the same rate as the check, both ripening approximately at the same time. It took the young tillers, however, about 10 to 14 days longer to mature. As shown by the height of the crop in Table 1 there is a tendency toward a decrease in height of plants as the time of fertilization is delayed. In all cases except the 100 pounds applied on March 29, 1928, there is a tendency for the height of the plants to increase with an increase in the amount of fertilizer applied.

Though the yields reported are only in duplicate and the differences are not enough to be conclusive, yet in the total yields there is

apparently a tendency for the February application to give the highest yields. This is reflected in the yields of threshed grain also, except in the 100-pound applications. Since there is very little difference in yield between the various dates of application, a consolidation of the dates in order to get enough varieties from which to figure probable errors was carried out and reported in Table 2. Fig. 1 shows graphically the effect of rate of fertilizer application on yield of threshed grain.

TABLE 2.—*Average yields from different rates of application of nitrate of soda on Vaughn barley at Davis, 1928.**

Treatment	Total crop in pounds per acre	Threshed grain, pounds per acre
Unfertilized	2,745±222	1,225±93
100 pounds per acre	4,660±240	2,035±90
200 pounds per acre	5,640±177	2,350±77
400 pounds per acre	6,820±286	2,720±99

*Each yield is the average yield of six separate sub-plats.

More extensive trials were carried on at the Imperial Valley Experiment Station[5] at Meloland by applying commercial sulfate of ammonia to both barley and wheat following sorghum. The only piece of land available was one on which Hegari, a grain sorghum, had been grown in rows alternately spaced narrow and wide, the wide spaces to facilitate root-cutting in connection with harvest (2). After the grain was harvested, the stalks were disked in, the seed planted, the fertilizer dissolved in water and applied with a sprinkling can, and then the plats irrigated. Plats, each 6½ feet by 20 feet, were separated lengthwise by 5-foot planted alleys and laterally by 4-foot unplanted borders or levees. Irrigation was by means of surface flooding between these borders or levees. No evidence of washing of the fertilizers from plat to plat in the same strip was noticed in the growth of the planted but unfertilized alleys between.

For barley there were five strips of plats each containing 11 plats. The fertilizer was applied to strips 1, 3, and 5, leaving strips 2 and 4 for check plats exclusively. For wheat the same arrangement was used, except that each strip had 12 plats. Comparisons are made in Tables 3 and 4 between the fertilized plats and the unfertilized checks. The checks for plats in strips 1 and 5 were taken from plats in strips 2 and 4 lying immediately alongside. The data for the checks to accompany each fertilized plat in strip 3 were averaged from the data of those two check plats in strips 2 and 4 lying on either side

[5]The details of the experimental work were carried out by L. G. Goar, Foreman, Imperial Valley Experiment Station.

of it. Three rates of application besides the checks and three times of application were investigated, making nine different fertilizer trials besides the unfertilized check. Each treatment was systematically replicated four times except one set with the barleys where there was room for but three series.

The rates of application were 100, 200, and 400 pounds of sulfate of ammonia per acre. The dates of application were at planting, December 23, 1927; just before the second irrigation, January 27, 1928; and just before the third irrigation, February 28, 1928. Two additional irrigations, making five in all, were given the crops before maturity. In this case the yield from the entire plat was harvested. The heights, yields of total growth, and yields of threshed grain are given in Table 3 for barley and in Table 4 for wheat.

Bessel's formula was used in computing the probable errors of the means of the fertilized plats as well as for the means of their respective unfertilized checks. The probable error of each increase was computed by securing the square root of the sum of the squares of the probable error of the mean of the fertilized plats and that of the corresponding unfertilized checks. Odds from the probable error were secured from the table of Pearl and Minor (6) and odds by Student's method from Love's (5) tables.

With both barley and wheat all 200- and 400-pound applications of sulfate of ammonia showed increases in height that are statistically significant. In the case of the 100-pound application only one-sixth of the trials showed significant increases, significance being judged in the cases above by odds of 30 to 1 or better. The greater the application of fertilizer on the same date the greater were the increases in height. There is a tendency toward a falling off in increase of height as the application of fertilizer is delayed. The crop where 400 pounds of fertilizer were applied to both barley and wheat on December 23 was enough taller than that to which the same amount was added on February 28 to be practically significant.

With the yields of the total crop all 200-pound and 400-pound applications give significant increases. Because of the increases due to heavier applications perhaps more recognition can be given the average values for the 100-pound applications than the actual odds would justify otherwise. In the case of the 400-pound applications the yield of total crop is more than doubled with the barley and in two out of the three cases, slightly more than doubled with the 200-pound applications. The 400-pound applications in one case doubled the yield of wheat and in another nearly doubled it. The date of applying the fertilizer has made no difference in yield of total crop

for which any significance can be shown. It is of interest to note that the mean yields of total crop for the 200- and 400-pound applications were higher when the applications were made on Januray 27.

From a practical standpoint the behavior of the yields of threshed grain are of the greatest interest. For this reason they are graphically shown in Fig. 2. Here the nearness to a straight line relationship be-

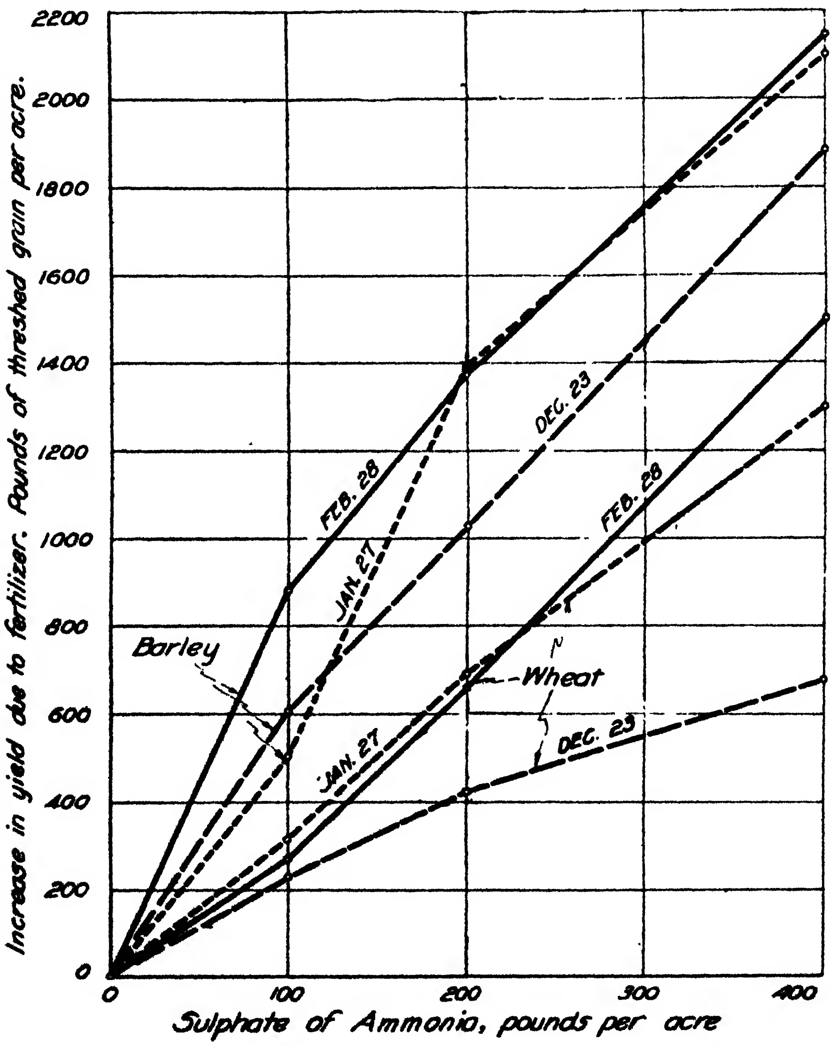

FIG. 2.—Effect of varying the rate and time of application of sulfate of ammonia on the increase in yield of Atlas barley and Escondido wheat following Hegari at the Imperial Valley Experiment Station, El Centro, Calif., 1928. The December 23 application was made at time of planting, 1927.

TABLE 3.—*Effect of sulfate of ammonia applications on the height, yield of total crop, and yield of threshed grain with Atlas barley following Hegari at the Imperial Valley Experiment Station, 1928.*

Applications of sulfate of ammonia: Rate in pounds	Time	Agronomic data: Fertilized	Unfertilized	Difference	Odds, Bessel	Student's method: Z	Odds
			Height of Crop in Inches				
100	Dec. 23, 1927	24.75±1.27	20.75±0.51	4.00±1.37	19.5	1.235	15
100	Jan. 27, 1928	24.75±1.11	21.25±0.67	3.50±1.28	14.4	1.15	13.2
100	Feb. 28, 1928	24.67±0.98	20.83±0.56	3.84±0.63*	20,000	2.93	36.2
200	Dec. 23, 1927	27.00±0.48	21.00±0.39	6.00±0.62	10^9+	8.49	2,499
200	Jan. 27, 1928	27.00±0.28	21.50±0.34	5.50±0.44	10^9+	4.91	586
200	Feb. 28, 1928	27.33±0.22	21.33±0.45	6.00±0.50*	10^9+	7.35	218
400	Dec. 23, 1927	31.00±0.28	20.75±0.32	10.25±0.42	10^9+	13.6	+5,000
400	Jan. 27, 1928	30.75±0.17	21.00±0.48	9.75±0.51	10^9+	7.5	1,999
400	Feb. 28, 1928	28.34±0.22	21.67±0.60	6.67±0.64*	10^9+	3.98	66
			Yield of Total Crop—Pounds per Acre				
100	Dec. 23, 1927	4,270±337	2,930±176	1,340±379	58.4	1.47	22.7
100	Jan. 27, 1926	4,435±250	3,140±232	1,295±342	92.0	1.60	27.7
100	Feb. 28, 1928	4,860± 41	3,070±199	1,790±209*	10^9+	8.6	311
200	Dec. 23, 1927	5,275±193	2,975±163	2,300±252	10^9+	6.69	1,660
200	Jan. 27, 1928	5,695± 46	2,785±116	2,910±123	10^9+	11.00	+5,000
200	Feb. 28, 1928	5,305±263	2,600±196	2,705±328*	10^9+	5.80	136

400	Dec. 23, 1927	6,870±235	2,825± 93	4,045±253	10^9+	6.08	1,040
400	Jan. 27, 1928	7,670±133	3,180±229	4,490±261	10^9+	5.76	915
400	Feb. 28, 1928	7,430± 41	3,460± 51	3,970± 66*	10^9+	3.61	54.4
Yield of Threshed Grain—Pounds per Acre							
100	Dec. 23, 1927	1,905±190	1,300± 88	605±209	18.8	2.16	58.9
100	Jan. 27, 1928	1,900±121	1,395± 97	505±155	34.4	1.37	19.0
100	Feb. 28, 1928	2,230± 49	1,350± 89	880±102*	10^9+	7.13	205
200	Dec. 23, 1927	2,335±111	1,310± 70	1,025±130	10^9+	3.82	285
200	Jan. 27, 1928	2,560± 25	1,165± 46	1,395± 52	10^9+	14.9	9,999
200	Feb. 28, 1928	2,500±136	1,125± 73	1,375±155*	10^9+	4.47	82
400	Dec. 23, 1927	3,155± 59	1,270± 86	1,885±104	10^9+	8.73	2,500
400	Jan. 27, 1928	3,470± 34	1,370± 98	2,100±101	10^9+	7.1	1,732
400	Feb. 28, 1928	3,705±230	1,570±215	2,145±316*	10^9+	4.41	80

*Average of three plats; all others average of four.

TABLE 4.—*Effect of sulfate of ammonia applications on the height, yield of total crop, and yield of threshed grain with Escondido wheat following Hegari at the Imperial Valley Experiment Station, 1928.*

Applications of sulfate of ammonia: Rate in pounds	Time	Agronomic data*: Fertilized	Unfertilized	Difference	Odds, Bessel	Student's method: Z	Odds
		Height of Crop in Inches					
100	Dec. 23, 1927	35.50±0.19	33.38±0.16	2.12±0.25	10^9+	4.02	322
100	Jan. 27, 1928	34.75±0.15	33.38±0.16	1.37±0.23	10^4+	2.11	55.5
100	Feb. 28, 1928	34.50±0.19	33.88±0.29	0.62±0.35	3.29	0.76	6.0
200	Dec. 23, 1927	38.75±0.68	34.00±0.24	4.75±0.74	10^4+	3.60	241
200	Jan. 27, 1928	39.00±1.09	34.00±0.24	5.00±1.09	510+	2.06	52.1
200	Feb. 28, 1928	38.50±0.85	33.75±0.22	4.75±0.88	10^3+	2.28	67.6
400	Dec. 23, 1927	43.75±0.58	33.88±0.22	9.87±0.61	10^9+	7.96	2,479
400	Jan. 27, 1928	42.50±0.80	33.88±0.22	8.62±0.83	10^9+	3.28	184
400	Feb. 28, 1928	39.75±0.70	33.63±0.16	6.12±0.71	10^9+	2.87	124
		Yield of Total Crop—Pounds per Acre					
100	Dec. 23, 1927	4,775±305	4,375±232	400±379	1.10	0.426	2.89
100	Jan. 27, 1928	4,570±187	4,170±209	400±280	2.03	2.20	61.9
100	Feb. 28, 1928	4,940±258	4,650±217	290±342	1—	0.575	4.13
200	Dec. 23, 1927	5,900±181	4,630±297	1,270±348	74.3	1.74	34.0
200	Jan. 27, 1928	6,495±466	4,675±307	1,820±560	34.4	4.03	328
200	Feb. 28, 1928	6,320±382	4,650±342	1,670±513	34.4	5.35	755

400	Dec. 23, 1927	7,750±332	4,630±305	3,120±449	10^5+	4.33	396
400	Jan. 27, 1928	8,840±412	4,355±264	4,485±490	10^9+	6.11	1,054
400	Feb. 28, 1928	8,330±214	4,200±253	4,130±327	10^9+	2.00	48.3
		Yield of Threshed Grain—Pounds per Acre					
100	Dec. 23, 1927	1,704± 70	1,510±122	230±141	2.69	0.66	4.94
100	Jan. 27, 1928	1,790± 63	1,475±104	315±123	10.9+	2.84	123
100	Feb. 28, 1928	1,930±111	1,660± 82	270±138	4.35	1.87	40.7
200	Dec. 23, 1927	2,080± 35	1,660± 98	420±108	112	1.73	33.5
200	Jan. 27, 1928	2,330± 97	1,640±109	690±153	416	18.1	9,999
200	Feb. 28, 1928	2,340±111	1,680±117	660±147	410	4.18	362
400	Dec. 23, 1927	2,435± 73	1,755± 78	680±105	10^5	3.26	180
400	Jan. 27, 1928	2,850±134	1,580± 88	1,300±158	10^9+	4.97	617
400	Feb. 28, 1928	3,040± 53	1,540± 61	1,500± 85	10^9+	78.5	9,999

*Each figure is the average from four different plats treated the same but replicated in rotation.

tween yield and rate of application of sulfate of ammonia is shown. All 200-pound and 400-pound applications show enough odds to be significant. The 100-pound applications for the most part show enough odds to be significant statistically by either Bessel's formula or by Student's method, though because of the way the two methods work out some show significance by but one method and that not the same each time. Both barley and wheat show a tendency for the January 27 and February 28 applications to cause a higher increase in yield of threshed grain for the 200-pound and 400-pound applications than for the applications made at planting time December 23.

In all of these figures the differences in odds as derived from Bessel's formula and from Student's method are somewhat different than has generally been reported. There is an impression derived from the literature, though not actually stated in so many words, that Student's method should give better odds in most cases than Bessel's formula method. In these tests the writer believes that the arrangement of plats should make either method applicable. If anything, Bessel's formula is in most cases theoretically at a disadvantage, but of the 54 different pairs of odds calculated by the two methods Bessel's formula gives the better odds (sometimes by far) in 44 cases.

LEGUME EXPERIMENTS

Experiments designed to subject barley and fenugreek to the after-effects of sorghum were conducted both in the greenhouse and in the field. For the greenhouse experiments a lot of soil (Yolo loam) was taken from the field, thoroughly mixed, and stored in sacks. Enough of this soil to carry on these tests was taken from the bags and thoroughly mixed twice. A 4-kg lot of the soil was placed in each of a number of weighed 1-gallon earthenware crocks the insides of which had been painted with two coats of a spar varnish. The soil was air dry. In November samples of roots were taken from various variety plats, the dirt removed by shaking, the roots washed, wiped, and then cut up. Three 2-gram samples were taken for sugar analyses by boiling immediately in alcohol with $CaCO_3$. A 10-gram sample was dried in the oven for moisture.

Either four or seven crocks were given equal weights of fresh roots. Where four crocks were used three were planted to Vaughn barley, 20 seeds to the crock, and the fourth kept unplanted to be sampled from time to time to follow the effect on nitrification. Where seven crocks were used for one treatment, the other three were planted to fenugreek, *Trigonella foenum-graecum*, 20 seeds per crock. Varying amounts of sucrose were added to other crocks and treated likewise. As greenhouse space was not available for about two months the crocks were

left in the dry state until they were wet up (850 cc per crock) with tap water on January 21, 1928, and moved to the greenhouse. The crocks were closed at the bottom, hence water was supplied by bringing each up to the initial wet weight every few days and recording the amount of water added. The plants were not allowed to go to maturity because of the near cessation of growth in the check crocks evidently due to a lack of available nitrogen. As vegetative growth only was desired from the fenugreek, that crop was harvested early also. On March 19 the plants were cut off practically even with the soil surface, dried in the laboratory for a week, and finally for about 48 hours in an oven at 70° C.

Table 5 gives the treatments, yields, and nitrates as shown by the phenoldisulfonic acid method on a 1 : 2½ water extract.

Table 5 brings out the fact that increasing the amount of sugars added either as pure sucrose or as total sugars computed to sucrose in the Honey sorghum roots decreased the yields of barley quite significantly, while these additions had had very little effect upon the yields of fenugreek, a naturally inoculated legume. This is more strikingly brought out by the curves in Fig. 3. Here the yield curve of barley as affected by sucrose nearly coincides with the yield curve of barley as affected by Honey sorghum roots when the latter is plotted on the basis of its sucrose content.

Table 5 brings out further that increased additions of sugars have repressed nitrification and with the heavier amounts have depressed the nitrates to a level below that in the soil at the start. Nitrates as they occurred in the soil on February 18 are shown in Fig. 3. Here, too, the two curves for the effect of varying amount of sucrose on nitrates from the pure sucrose and from Honey sorghum nearly coincide. The nitrates in the soil in the uncropped crocks at a time midway between planting and harvest might be expected to represent, as well as at any other time that nitrates were run, the amount of nitrates that would influence crop growth in the crocks cropped to barley. On February 4 growth was just well started, while on March 10 growth of the barley was nearly finished with harvest on March 19, 1928. The nitrates on March 31, 12 days after harvest, give the effect of the additions on nitrification for a longer time. In Fig. 3 there is a close parallelism between yield curves and curves of nitrates in the uncropped crocks of the same treatments. In fact if the nitrate curves were raised by raising the zero of their graphs, they could be made almost to coincide with their respective yield curves of barley. There is no parallelism or apparent relation between the nitrates and the yield of fenugreek, however.

TABLE 5.—*Yield of barley and fenugreek plants from crocks of Yolo loam soil (4 kg per crock) to which varying amounts of Honey sorghum roots, roots of other varieties, and sucrose had been added and nitrates occurring periodically from the same additions but uncropped, 1928.*

Variety	Additions: Fresh roots, grams	Additions: Total sugars as sucrose,* grams	Yield in grams per crock† Barley	Yield in grams per crock† Fenugreek	Nitrates, equivalents per million of dry soil‡ Feb. 4	Feb. 18	Mar. 10	Mar. 31
Honey sorghum	2.5	0.20	1.89±.024		0.69	0.89	0.90	0.82
	5.0	0.39	1.87±.050		0.65	0.68	0.74	0.86
	10.0	0.78	1.48±.023	4.58±.39	0.49	0.40	0.68	0.67
	20.0	1.56	1.14±.041		0.35	0.25	0.29	0.32
	40.0	3.12	0.79±.005	4.54±.26	0.12	0.08	0.12	0.09
Check	—	—	2.24±.018	4.77±.04	0.80	0.87	1.09	0.92
Sucrose		0.10	2.31±.061	4.87±.16	0.76	0.76	0.93	1.31
		0.21	2.10±.026		0.65	0.80	0.81	1.26
		0.46	1.93±.020		0.65	0.61	0.75	0.77
		1.00	1.27±.019	4.96±.08	0.28	0.26	0.56	0.34
Double dwarf milo		0.07	2.15±.011	4.52±.21	0.66	0.74	0.73	0.96
Broom corn		0.71	1.40±.014		0.42	0.48	0.54	0.73
KingPhillip Indian corn		0.013	2.14±.015	5.43±.03	0.57	0.78	0.66	0.72

*Sugars by the picric acid method of Willaman and Davison (10).

†Each yield the mean yield of three crocks. Probable errors computed by Bessel's formula.

‡Nitrates by the phenoldisulfonic acid method, each a single determination. Nitrates run on the dry soil at start of experiment January 21 gave 0.35 equivalent per million of dry soil.

It should be borne in mind that there are two factors which would modify the exact correlation between the yield curves of barley as affected by varying amounts of pure sucrose and sucrose applied in Honey sorghum or any other kind of roots. The sorghum roots contain a small amount of easily decomposable proteins which would furnish water-soluble nitrogen to the soil solution. This would tend to increase yields of barley and the nitrates in the uncropped soil. Added with the sorghum roots are some starches, hemi-celluloses, and celluloses not taken into account by the analyses for sugars, whose action on microbiological activities in the soil would be in the same direction as that caused by sucrose but progressively slower.

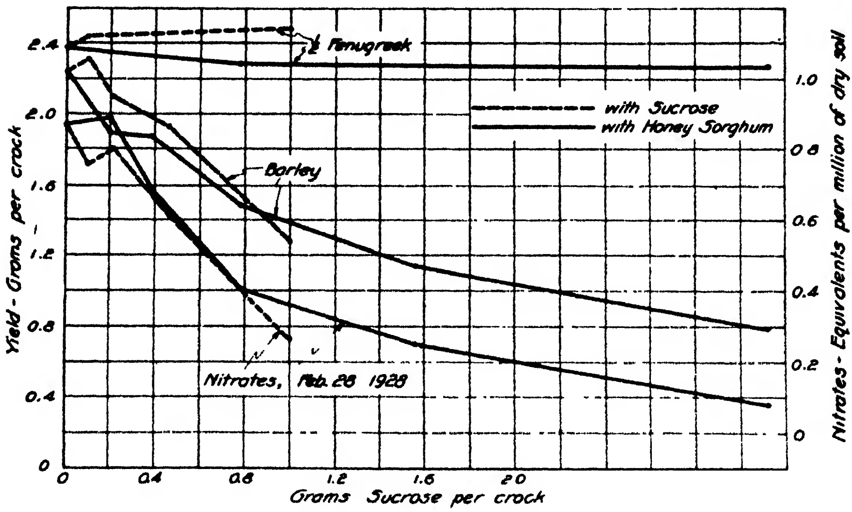

FIG. 3.—Effect of varying the amount of sucrose and Honey sorghum roots on nitrification and on yields of barley and fenugreek with Yolo loam soil in crocks. The amounts of Honey sorghum roots added are plotted according to total sugars as sucrose which they contain.

To measure the effect of previous crop treatments, including sorghums, on the growth of barley and fenugreek in the field, a series of plats were laid out under irrigation at Davis in the spring of 1927, each treatment being replicated five times. Each plat was 12 feet wide (to accommodate four rows) and 30 feet long. Four plats lengthwise, or 120 feet, and three plats laterally, or 36 feet, accommodated the area in the larger one-tenth acre leveed plat. These 25 sub-plats, together with other miscellaneous crops, were accommodated in three one-tenth acre plats. The sub-plats were arranged to give the maximum distance between replications of the same treatment in each direction. After the summer crops had matured, the

above-ground growth was removed and the land disked. On December 7, 1927, alternate strips of Vaughn barley and fenugreek were drilled in lengthwise of the larger plats in such a way that one-half of each sub-plat was planted to barley and the other half planted to fenugreek. In May, 1928, 5 feet were cut off the end of each sub-plat, making the length of each 20 feet. The barley was harvested and yields secured by taking two adjacent 20-foot drill rows or the yield from 20 square feet, weighing the total crop, and then the threshed grain in grams. The fenugreek was harvested in a mature condition and the total crop weighed. As these sub-plats were arranged in such a way as to question the advisability of using Student's method, probable errors were computed by Bessel's formula only. Table 6 gives the heights and yields from these tests.

TABLE 6.—*Effect of previous treatment on the height and yield of Vaughn barley and on the yield of fenugreek in the field, Davis, 1928.*

Previous treatment (1927)	Data on succeeding (1928) crops			
	Vaughn barley			Fenugreek in pounds per acre of total crop
	Height in inches	Pounds per acre		
		Total crop	Threshed grain	
Broom corn	28.6±0.46	2,800±125	1,300± 57	5,450±175
Fallow	34.4±1.25	5,060±271	2,260±102	4,350±225†
Indian corn*	30.6±0.62	3,060±250	1,440±127	5,510±182
German millet	32.6±0.59	4,140±188	1,900± 59	5,010±286
Honey sorghum	27.4±0.62	2,200±169	985± 68	5,080±225

*King Phillip variety.

†Average of but four replications as the fifth was too low in yield, due to a weedy spot, to warrant including.

During the active growing season there was no noticeable difference in the growth of fenugreek, but the barley showed marked differences, many of the sub-plats of the latter standing out distinctly as might be expected from the difference in heights as given in Table 6. Barley following Honey sorghum is lower in yield of total crop than that following Indian corn by 860±302 pounds of total crop per acre and by 455±144 pounds of threshed grain per acre. These differences give odds of 17.4 and 29.4, respectively, according to the table of Pearl and Miner (6). The latter is just slightly below the odds of 30 to 1 generally used as a test of significance. Barley following both broom corn and Honey sorghum is markedly less than that following fallow. Barley following Indian corn is not quite so low as in the other two cases.

On the other hand, there is no great difference in yield of fenugreek following any of these treatments, except possibly that following fallow. Taking the yields following fallow as the basis of comparison,

these data show that under the conditions of the experiment Indian corn, broom corn, and Honey sorghum have depressed the following crops of barley markedly, the broom corn and sorghum more than the corn. None of these crops have depressed the following crop of fenugreek. If anything, the fallow has depressed the yield of fenugreek below the level following the crops tried out.

DISCUSSION

With the assumption that sorghum residues contain high amounts of sugars, the results which have been secured by these experiments could have been predicted qualitatively from current soil microbiological theory (9, chapter 19); but the results from the field tests without the laboratory analyses of either soil for nitrates or sorghums and corn roots for sugars also could have been predicted qualitatively on the basis of the first theory to which reference was made, namely, that sorghums take so much of the available plant food from the soil that there is not enough left to meet the needs of the crops following. In conditions where nitrogen is the element to become lacking first, we could predict that applications of nitrogenous fertilizers would increase the following crops of grain and that inoculated legumes securing their nitrogen from the air could make normal growth, provided some other essential element or elements in available form were not also reduced to such a low level as to limit the growth of the legumes.

The decrease in yield of barley in the crocks shown in Table 5, however, cannot be explained on the basis of the heavy use of nitrogen by the sorghum crop previous, since the soil used, so far as the writer knows, has never been subjected to cropping by the sorghum plant, at least not within the last eight years. The tap-water cultures of wheat conducted by Breazeale (1) likewise cannot be explained by this theory. That this theory to some extent is operative in the field is self-evident and undoubtedly accounts for some of the reduction in yield of barley following sorghums and corn below that following fallow. It is generally known that a fallow soil will build up the amount of nitrates for the succeeding crop, if it has been properly prepared and kept free of plant growth. Most crops that make heavy growth will reduce the available elements essential for plant growth to a much lower level than that to which the practice of fallowing would have elevated them.

With evidence limited to the yields of barley in crocks to which corn and sorghum residues have been added, to the water-cultures of wheat described by Breazeale, and to the field trials of grains follow-

ing sorghums and corn previously reviewed (3), it would be reasonable to suppose that this was caused by the presence of a "toxic body" which could arise in the decomposition of the sorghum residues. But with evidence of marked response of barley and wheat to applications of nitrogen fertilizers following sorghums, together with the lack of any considerable injury to legumes following sorghums, the "toxic body" theory is inadequate.

The toxin theory as the cause of the injury of one plant on itself to another plant succeeding it was advanced a number of years ago. The benefits due to fertilizers were explained by that theory as being caused by the action of the fertilizers breaking down the toxins. The toxin theory as an important factor in plant production in normal soil has largely been discredited because most of the results can be explained as being due directly to the fertilizer applied and no substance has been isolated from normal soils in high enough concentrations to injure plant growth. If the toxin theory is here applied, a toxin with very special properties must be forthcoming, namely, one that is toxic to barley, wheat, and a number of other non-leguminous crops; one that is destroyed in proportion to the nitrogenous fertilizer applied to the soil; and one that is only slightly injurious, if at all, to the growth of fenugreek and alfalfa, the latter on the basis of farmers' successful experiences with that crop following sorghums in Imperial Valley. In the outstanding case of soil toxicity in the western United States, namely alkali, barley and wheat have demonstrated a greater resistance to this than the legumes generally.

Neither of these two theories can be used to explain all of the observations and yields secured from growth studies. When the laboratory analyses made in connection with these growth studies are considered these theories are much less applicable. The theory of competition between micro-organisms of the soil, on the one hand, and the non-leguminous crops following sorghums, on the other, seems applicable to all field observations, practically all growth studies, and to the results of all laboratory analyses and data that have come to the attention of the writer. The curves in Fig. 3 strongly suggest that the sugars in the sorghum roots are the primary cause that stimulates the soil micro-organisms to such vigorous competition for available nitrogen in the soil solution.

From the data showing that barley and wheat following sorghums give marked increases in growth from nitrogenous fertilizers, that these increases are roughly proportional to the rate of application of the nitrogenous fertilizers, and that fenugreek, a legume naturally inoculated under California conditions, gives normal growth, it may

be concluded that lack of available nitrogen is the cause of the injury. Some light should be thrown on the maximum yields that might be expected from nitrogenous fertilizer applications to non-legumes following sorghums.

By comparing the shape of the curve in Fig. 1 with the shape of Mitscherlick's curve (8, page 32), which corresponds very closely to the theoretical curve of Mitscherlick's statement of his law of the lacking factor, it would be supposed that the yield there is at least 60 to 70% of the maximum, though the fact that part of the curve corresponding to the lower part of Mitscherlick's curve is lacking would preclude too close a comparison. From this it might be surmised that further additions of fertilizers under the conditions of the experiments at Davis might not markedly increase the crop further. But even if with most of the curves in Fig. 2 the bottom ends are lacking, still these curves are so close to being straight that it might be reasonable to expect rather large increases over and above those shown in Fig. 2 by heavier applications than 400 pounds per acre of ammonium sulfate. Whether these additions would be profitable is another question.

Though one year's results ordinarily are not sufficient to form the sole basis for determining the practicability of fertilizer practice under a given set of conditions, yet the results of a series of tests sufficiently replicated should give some information for making a preliminary estimate. The results secured at Davis and Imperial in 1927 (3) helped to substantiate the theory, but the 1928 tests and those to follow were planned to give some idea of the practicability of a fertilizer program. Table 7 gives the increases in yield of threshed grain due to fertilizer applications of different rates, the value of increased yield, the cost of the fertilizer applied, and the net returns due to application of the fertilizer.

From the average selling price of barley f.o.b. Davis of $1.35 per cwt is subtracted $.07 for hauling and $.105 for second-hand sacks to contain the crop. Generally, one sack is required per cwt of barley. Though undoubtedly the increased yield costs slightly more to harvest, most all of the "combining" done as "custom" work in these districts is at a flat rate per acre regardless of the yield. Any slight increase in harvesting cost should be offset, however, by the increase in straw for sheep pasture. This makes a net price of $1.175 clear of sack and hauling costs. At Imperial sack and hauling costs used in computations are the same as for Davis for barley, or $0.175, but a little less for wheat due to the 135 pounds to the sack, or a total of $0.145. As the average price farmers received from their barley was

estimated at $1.535 per cwt and for wheat at $2.125 for 1928 the net price, free of the costs above, would be for barley $1.36 and for wheat $1.98.

Estimates[6] of fertilizer costs are computed on the basis of $61.70 per ton for nitrate of soda in cars at Davis, $70.50 per ton for sulfate of ammonia at warehouse at El Centro, $1.40 per ton for hauling from town, and $0.55 per acre for application of the fertilizer.

It should be remembered that slight differences in the selling price of barley or wheat or slight changes in the price of fertilizer may make material changes one way or the other in the relative profit from applying fertilizer. With conditions as they have occurred this past season at Davis with regard to season, yield, price, etc., as a basis, it is within the realm of possibility that the application of from 100 to 150 pounds of nitrate of soda and perhaps a like amount of sulfate of ammonia to barley following grain sorghums would prove profitable where either rainfall or irrigation is sufficient to wet up the subsoil to the depth that the sorghum crop has dried it out, probably to 3 to 4 feet where the sorghum has been well irrigated and 6 to 8 feet where the sorghum was grown without irrigation under California conditions.

With conditions as they have been in Imperial Valley for the last year as a basis, it is within the realm of possibilities that from 100 to 400 pounds of ammonium sulfate per acre or possibly even more might prove profitable to apply to small grains following sorghums, if any farmer can be found there who plants small grains in that crop sequence. The yields of wheat and barley following sorghums have been so disastrously poor in the Valley that this practice, formerly attempted, has been almost completely abandoned.

How much of a loss per acre is involved in following sorghums with wheat or barley would be hard to estimate as it involves the competition with alfalfa which grows a successful crop or the leaving of the land idle until it has recuperated. At any rate the profit from the use of fertilizer as it appears in Table 7 or similarly derived for other prices, costs, and yields must be enough over the cost of the fertilizer and its application to offset this initial loss due to planting the small grain in the first place. This initial handicap for Imperial Valley conditions may be enough to put the sorghum-fertilized-small-grain-crop sequence out of consideration. If that were the case, results here secured are sufficient to warrant consideration of experimenting

[6]These estimates are believed to be approximately correct as they are based on current quotations, freight rates, etc.

with other crops whose monetary return per acre is greater than that of the small grains.

As early as 1901 Krüger and Schneidewind, cited by Waksman (9 page 512), used legumes to show that the injury to other plants from incorporating large amounts of cellulose into the soil was not due to toxins formed in the decomposition of the cellulose. No serious attempt has been made to take advantage of the opportunity presented by these scientific findings. What more natural farming practice could be followed than to plant legumes under conditions where they would grow normally and where non-legumes are stunted?

TABLE 7.—*Preliminary estimate of the net returns per acre from the use of nitrogenous fertilizers on small grains following sorhgums, 1928.*

Fertilizer Pounds per acre	Fertilizer Time of application	Increase in yield, pounds	Increase in field value	Cost of fertilizer and its application	Estimated net return
		Davis—Nitrate of Soda on Vaughn Barley			
100	——	810	$9.52	$3.70	$5.82
200	——	1,125	13.22	6.85	6.37
400	——	1,495	17.56	13.15	4.41
		Imperial Valley—Sulfate of Ammonia on Atlas Barley			
100	Dec. 23, 1927	605	8.23	4.15	4.08
100	Jan. 27, 1928	505	6.87	4.15	2.72
100	Feb. 28, 1928	880	11.97	4.15	7.82
200	Dec. 23, 1927	1,025	13.94	7.75	6.19
200	Jan. 27, 1928	1,395	18.97	7.75	11.22
200	Feb. 28, 1928	1,375	18.70	7.75	10.95
400	Dec. 23, 1927	1,885	25.64	14.95	10.69
400	Jan. 27, 1928	2,100	28.56	14.95	13.61
400	Feb. 28, 1928	2,145	29.17	14.95	14.22
		Imperial Valley—Sulfate of Ammonia on Escondido Wheat			
100	Dec. 23, 1927	230	4.55	4.15	0.50
100	Jan. 27, 1928	315	6.24	4.15	2.09
100	Feb. 28, 1928	270	5.35	4.15	1.20
200	Dec. 23, 1927	420	8.32	7.75	0.57
200	Jan. 27, 1928	690	13.66	7.75	5.91
200	Feb. 28, 1928	660	13.07	7.75	5.32
400	Dec. 23, 1927	680	13.46	14.95	—1.49*
400	Jan. 27, 1928	1,300	25.74	14.95	10.79
400	Feb. 28, 1928	1,500	29.70	14.95	14.75

*Minus sign signifies a loss.

The planting of legumes following the incorporation of large amounts of straw or other carbonaceous matter into the soil should prove very promising in securing the benefits of both the carbonaceous matter and the legume concurrently.

With injury from sorghums manifest even when the roots only are left in the ground, other means besides burning or pasturing off the stubble must be sought. Farmers of the Imperial Valley have been planting alfalfa immediately following sorghums for a number of years and have secured normal or nearly normal crops. This crop sequence points out as good a procedure as any now available to avoid the injury following sorghums. To alfalfa may be added fenugreek on the basis of yields reported in Tables 5 and 6. Hawkins (4) received normal growth from peas. Because the theory fits the observations and sorghum injury almost to a nicety, it seems safe to predict that almost any legume either naturally or artificially inoculated should yield as well following sorghums as following any other crop, except where the level of some essential element besides nitrogen is already so low that the competition from the micro-organisms would further lower it to a point where it would limit the growth of the legume. Where legumes follow sorghums on heavy land, the poor physical conditions described by Breazeale may bring in other complications as to aeration of the soil, water penetration, etc.

Though other ways to dodge the injury of sorghums to succeeding crops have been suggested (1, 3), still the most promising way available at the present time, where the injury is very considerable, is undoubtedly to be found in growing legumes, provided any are available that are well adapted to local conditions.

SUMMARY

1. Nitrate of soda applications of 100, 200, and 400 pounds per acre to replicated plats at Davis gave significantly increased yields of barley following White Durra. The average yields were 810, 1,125, and 1,495 pounds per acre, respectively, over 1,225 pounds, the average yield of the unfertilized check plats.

2. Significant increases in yield were secured with 200- and 400-pound applications of sulfate of ammonia to barley and wheat from replicated plats in the Imperial Valley following Hegari. All 400-pound applications and some 200-pound applications more than doubled the yields of barley. In general, higher yields were secured by applying the fertilizer 35 and 67 days after planting than at planting time.

3. In triplicate pot experiments where different weights of sorghum roots, corn roots, and sucrose were added to the soil, barley decreased in yield with an increase in sorghum roots and sucrose added; nitrates in uncropped pots were progressively depressed by increased additions of sorghum roots and sucrose; and fenugreek, a legume naturally inoculated at Davis, made normal growth. A close relationship is indicated between the depression of nitrates by sorghum roots and that by an equivalent amount of sucrose. Likewise, a relationship between barley yields and nitrates thus depressed is indicated.

4. In replicated field trials barley was depressed in yield progressively by following millet, corn, broom corn, and sweet sorghum below the yield following fallow, while fenugreek made normal growth on all of the plats previously in crop, in fact yielding higher than those following fallow.

5. The theory of sorghum injury as due to a heavy draft on available essential elements cannot satisfactorily explain observations under 3 above, while the toxin theory cannot explain 1, 2, and 4. The theory of competition between micro-organisms and the crop plants for nitrogen and possibly other essential elements very satisfactorily explains all of these observations.

6. The chance of profit from the use of some rates of application of nitrogenous fertilizers where small grains normally follow sorghums seems hopeful on the basis of increased yields secured, present prices, and increased costs of production involved. Where small grains do not normally follow sorghums because of poor yield, this initial loss must be less than the profit shown for the fertilizer applications themselves to make the sequence of sorghums and fertilized small grains profitable.

7. The practically normal growth of alfalfa and fenugreek following sorghums suggests that planting a legume may be the best way to dodge "the injurious after-effects of sorghum."

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NOTE

RELATION OF STAND TO YIELD IN CORN

It is a generally accepted principle that reduced stands of corn are very materially compensated for by increased development of each plant under such reduced stands. For this reason, correction of yield results to compensate for reduced stand is regarded by agronomists as a dangerous practice. In view of these facts, the case herewith reported in which yield was reduced in almost exactly the same ratio as the reduction in stand was rather surprising to the writer and may be of interest to other workers.

In the course of an experiment carried out during 1927 in which a seed study was being made, 82 individual ear rows were grown. These rows showed a decided variation in stand and it was quite evident that comparative yields had been very decidedly influenced by such variation. A careful analysis was made, therefore, of the relation between successive increments of stand and successive increments of yield. The method of analysis and results are shown in Table 1.

The rows as harvested were 18 hills in length, and the stand varied from 17 to 52 stalks per row as the first horizontal column of the table shows. The rows were grouped into "stand classes," the extremes and class centers constituting the column headings of the table. The first class, for instance, consisted of all of the rows having a stand ranging from 17 to 19 stalks per row. There was only one such row. The next class ranged from 20 to 22 stalks, with a class center of 21. There were three such rows, and so on. It will be noted that each row is entered in its own column, according to its stand, and the stand and yield of each such row are shown. For example, in the last class mentioned, namely, that including the limits 20 to 22, three rows have respective stands of 22, 20, and 20, and respective yields of 6.25, 5.61, and 5.64 (shelled corn dry matter per row). At the bottom of each column is given the mean yield of all of the rows entered in the column. It will be noted that there is a progressive increase in the mean yield from column to column up to that with a class center 45. The two classes above this very probably would have shown further increases had there been more individuals in them.

To determine how closely the progressive increase in yield is related to the increase in stand, the two sets of figures under the ruled line have been worked out. The first or upper set represents the successive increments of stand in o/o when the "ideal" stand of 45 is compared with each of the other "stand units." For instance, the

TABLE 1.—*Relation of stand to yield of corn.*

	17 19 18	20 22 21	23 25 24	26 28 27	29 31 30	32 34 33	35 37 36	38 40 39	41 43 42	44 46 45	47 49 48	50 52 51
	17–5.96	22–6.25	25–8.71	27–8.24	30–10.84	34–10.39	37–12.08	38–11.63	43–12.22	44–12.90	49–13.75	50–13.64
		20–5.61	24–7.05	27–7.73	29–8.70	32–11.12	37–12.18	38–12.62	42–12.20	45–14.80	48–11.98	51–12.17
		20–5.64	23–6.74	27–7.06	30– 8.38	34– 9.65	36–12.96	39–12.38	42–11.90	46–11.36		
			23–4.71	26–6.47	20–10.94	34–11.28	35–12.01	38– 9.96	43–11.91	46–12.60		
				27–8.17	29– 7.53	32– 9.05	36–11.52	39–12.31	43–13.60	45–13.41		
				28–8.45	31– 8.85	34– 9.71	35–11.56	38–11.60	41–10.70			
				27–8.27	31– 7.27	33–11.54	37–14.51	38–10.55				
				26–9.01	31–10.58	32– 9.41	37– 9.75	39–11.35				
						33– 7.62	36–11.04	39–12.16				
							35–10.15	40–10.97				
							36– 9.13	38– 9.34				
							35– 9.75	38– 9.17				
							37– 9.53	40– 9.76				
							36– 7.95	40– 9.80				
							37–11.95	40–12.00				
							36– 8.68	39– 8.34				
								40–11.42				
								39–13.33				
Mean yield	5.96	5.83	6.80	7.93	9.14	9.97	10.92	11.04	12.09	13.01	12.86	12.90
Stand increments o/o			114.20	87.50	66.70	50.00	36.40	25.00	15.40	7.20		
Yield increments o/o			123.20	91.30	64.10	42.30	30.50	19.00	17.90	7.60		

Average of stand increments 50.8
Average of yield increments 49.5

increase of stand in the column with a class center of 45 over the column with a class center of 42 is 7.2. Similarly, the lower set of figures represents the successive increments in yield when the mean yield of the rows in the "ideal" column 45 is compared successively with the mean yields of each of the other rows. Thus, the mean yield per row of those in the class represented by 45 stalks per row is 7.6% greater than those in the class represented by 42 stalks per row. In other words, an increase of 7.2% in stand was accompanied by an increase of 7.6% in yield. Comparing the increase in yield with the increase in stand in each of the columns where these figures appear, it is found that in most cases they show very good agreement. When the averages of the stand and yield increments, respectively, are determined, these are found to be very close. The figures are 50.8% and 49.5%, respectively, as shown at the extreme right of the table.

It is evident, therefore, that in this particular case a 100% correction for stand is fully justified in order to bring the rows to a comparable basis.

The field on which this corn was grown was in a high state of productivity and a plausible explanation of the results obtained would seem to be that the available plant food was sufficient to permit maximum development of each plant even where the "ideal" stand occurred.—P. J. Olson, *Assistant Agronomist, North Dakota Experiment Station, Fargo, N. Dak.*

BOOK REVIEWS

SOLUBILITIES OF INORGANIC AND ORGANIC COMPOUNDS

By Atherton Seidell. New York: D. Van Nostrand Co., Inc., VI+ 1001–1571 pp. Supplement to Ed. 2. 1928. $8.

Those who have found the second edition of Seidell's "Solubilities of Inorganic and Organic Compounds" useful in their work will welcome his recent supplement to that edition which appears under the same title. The new supplement covers the quantitative solubility data published in scientific periodicals during the years 1917 to 1926, inclusive. Much new material as well as more recent and accurate work on old material is thus made available to those interested. The arrangement is the same as that in the second edition and the index covers both the old and the new volumes.

Although many agronomists would have little use for a reference work of this kind, those dealing with chemistry and soil physics, especially, may find useful many data given. (R. C. C.)

HANDBOOK OF FERTILIZERS

By A. F. Gustafson, New York: Orange Judd Publishing Co., 122 pp., 18 figs. 1928.

In the words of the author, this little book "is an attempt to supply accurate, up-to-date information as to the source and makeup of commercial fertilizers." Following the introductory chapter on "Requirements for Plant Growth," three chapters deal with the nitrogen, phosphate, and potash fertilizing materials. Chapter V deals with the effect of fertilizers on soils and crops. Three chapters follow dealing with factory and home mixing, and the purchase of fertilizers. The last chapter deals with "Liming in Relation to Fertilizer Practice." An index is included.

Farmers, extension workers, and others who desire up-to-date descriptive information concerning the nature and uses of fertilizer materials and fertilizers, including those that have come upon the market during recent years, will find such information in this book. The language is simple and easy to follow. Those not thoroly versed in chemistry will not find the book difficult to read. (F. C. B.)

PRINCIPLES OF SOIL MICROBIOLOGY

By Selman A. Waksman. Baltimore: Williams & Wilkins Co. 897 pp. 1927. $10.

This book is a comprehensive and technical discussion of all phases of soil microbiology. It is divided into four parts as follows: (A) Occurrence and differentiation of micro-organisms in the soil (50 pages); (B) isolation, identification, and cultivation of soil micro-organisms (310 pages); (C) chemical activities of micro-organisms (250 pages); and (D) soil microbiological processes and soil fertility (225 pages).

Of these major sections, Part A is limited to a single chapter, while Part B contains 13 chapters, each of which, with one exception, deals with some special group of soil mirco-organisms. Part C contains nine chapters dealing with energy relationships of the soil micro-organisms and such activities as decomposition of organic matter, oxidation and reduction, nitrogen fixation, and sulfur transformations. Part D contains the material having the greatest bearing on practical agronomic problems and includes the following chapters: The soil as a medium for the growth and activities of micro-organisms; transformation of minerals in the soil; transformation of organic matter in the soil; microbiological analysis of soil as an index of soil fertility; soil microbiological equilibrium; influence of air drying and partial sterilization upon the activities of micro-organisms in the soil; influence of environmental conditions, soil treatment, and plant growth upon micro-organisms and their activities in the soil; soil as a habitat for micro-organisms causing plant and animal diseases; soil inoculation; history of soil microbiology, its past, present and future.

In parts C and D, in particular, the author writes with the authority of one who has pursued much personal investigation in the subjects discussed. The whole book, in fact, is considerably more than a mere review of literature, thanks to the writer's wide experience in the field covered. It goes far toward making soil microbiology appear as a science in itself, which, in the author's opinion, is a fundamental one from the standpoint of agronomy. Although emphasizing the importance of the subject, the writer wisely refrains from making too glowing promises as to its possible contributions toward the future of agriculture. (H. J. C.)

AGRONOMIC AFFAIRS

MEETING OF NEW ENGLAND SECTION

The fifteenth annual meeting of the New England Section of the American Society of Agronomy will be held jointly with Section O of the American Association for the Advancement of Science in New York City, Friday, December 28. A symposium program on "Pasture Management Research" is being prepared and will be printed in the December number of the JOURNAL. An evening banquet will be followed by a program including the address of the retiring vice-president of Section O.

NEWS ITEMS

J. H. LEFFORGE, formerly instructor and research fellow in the Division of Agronomy and Plant Genetics at the University of Minnesota, has been appointed Assistant Professor of Agricultural Botany in the Department of Agronomy at Purdue University.

R. W. DONALDSON has been elected to the position of Extension Specialist in Agronomy at the Massachusetts Agricultural College to succeed J. P. Helyar who has accepted a position with the American Agricultural Chemical Company.

ON SEPTEMBER 6 a group of agricultural leaders and business men assembled at Wakefield, Rhode Island, to pay tribute to the work of Dr. B. L. Hartwell, retiring agronomist and director of the Rhode Island Experiment Station. After a banquet, Dr. Hartwell was presented with a loving cup as a token of appreciation of his services to the agriculture of Rhode Island.

DR. C. F. MARBUT, Chief of the Soil Survey, Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, was recently presented with a diploma of membership in the Berlin Geographical Society in recognition of his services to soil science.

N. T. NELSON, formerly with the Tobacco Substation at Windsor, Connecticut, has been made Chief of the Tobacco Division of the Experimental Farm at Ottawa, Canada.

CORRECTION BY F. D. RICHEY

In the article on "Equality of Kernel Row Numbers in Reciprocal Corn Crosses," by F. D. Richey and H. S. Garrison, appearing in the October number of this JOURNAL, 0.94 should be substituted for 1.21 in comparison No. 20 in Table 1 (page 1070) under the heading of difference in number of kernel rows.

CORRECTION BY P. B. KENNEDY

In Volume 19 of this JOURNAL on page 751 in Table 1 of the article by P. B. Kennedy on "An Alkali Forage Weed (*Bassia hyssopifolia*)," the nitrogen-free extract of *Bassia hyssopifolia* (moisture free) should be recorded as 34.04% instead of 24.04%.

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A NATIONAL PROGRAM FOR SOIL RESEARCH[1]

A. G. McCALL[2]

In the selection of the title for my presidential address I have not been unmindful of the fact that the agronomist's chief interest centers around crop plants rather than around the soil in which his plants are grown. I hope, however, to show that the promotion of a successful system of plant husbandry must be based upon a comprehensive program of soil research.

The study of soils involves consideration of the mutual relations of climatic conditions, soils, plants, and animals, including man. The subject is so complicated that most students of soils are content to confine themselves to a single group of soil problems, hence the necessity for the consideration of a soil research program built upon a foundation not only broad enough to include a study of soil characteristics and the interrelations of soil and plants, but strong enough to support the study of plant food resources and their mobilization.

During the earlier periods of our agricultural development when land was abundant and labor plentiful and cheap, increased production was easily secured by expanding the acreage under cultivation. Present economic conditions would seem to call for a program which involves a contraction of the acreage under cultivation but increased total production to meet the demands of a rapidly increasing population. Marginal lands must be identified and eliminated for the present and our energies directed toward increasing the productivity of each unit and persuading the man on the farm to strive toward the production of twice as much grain per acre with a corresponding decrease in acreage and labor costs. The main objective of

[1]Presidential address read at the annual meeting of the American Society of Agronomy at Washington, D. C., November 22, 1928.

[2]Chief, Soil Investigations, Bureau of Chemistry and Soils, U. S. Department of Agriculture, Washington, D. C.

such a program is the establishment of such methods of soil management as will encourage the farmer to increase productivity without necessarily increasing total production, except as required to meet the demand for farm products that can be sold at a price that will cover the cost of production plus a reasonable margin of profit to the producer.

The task of formulating and putting into effect a national program of soil research is not an easy one because of the wide diversity of interests involved and the variety of the conditions encountered in the various regions of the United States. It is not my purpose to attempt to set up new agencies of research, but to attempt to show how the work of the many agencies already in the field may be harmonized to the mutual advantage of both the research worker and the farmer. Fortunately, we have in our state experiment station system the necessary organizations to function as the units in a comprehensive national program. The program which I have in mind involves the cooperation of the state experiment stations with the federal government in a plan of research mutually agreeable to both. This plan would include (1) the completion of the soil survey already in progress, (2) the inauguration of a program of fertilizer research based on the soil survey, (3) a study of methods for the control of soil erosion, (4) a survey of the soil organic matter of the United States, and (5) finally, a study of methods for the diversion or utilization of surplus products of the soil and the waste materials of the farm so that they become the raw materials of industry.

THE SOIL SURVEY PROGRAM

The soil survey is a good example of the mutual benefits to be derived from the efforts of the United States Department of Agriculture working cooperatively with the states in a comprehensive plan for securing a complete inventory of the soil resources of the entire country.

During the progress of the soil survey approximately half of the arable land of the United States has been surveyed and mapped. A high degree of accuracy has been reached in making soil maps. Soil surveying represents the mechanics of a new science, and it has been necessary to work out methods step by step. The geological relations, the great variety of materials of different composition from which soils have developed, the various modes of soil formation, all of which have a bearing on the final characteristics of the soil, had to be worked out as these problems were met with in the field, and the whole system of soil classification gradually perfected.

Each year has seen progress, and in recent years a stage of development has been reached which combines fundamental scientific principles with accuracy in soil classification.

In the application of the soil survey, the individual is usually interested in a particular locality of limited extent. The states are interested primarily in the lands within their borders, whereas the national government is interested in the whole country. For the sake of uniformity and in order that all interested parties may think of soils in the same terms, the Bureau of Soils has worked out and put into effect a system of soil classification and naming broad enough to embrace the entire country and detailed enough to permit the recognition of minor differences.

To insure continuous adherence to the idea of uniformity in classifying soils throughout the United States and at the same time to provide for proper considerations of local conditions, it has been found desirable that federal and state agencies should work together in making soil surveys in any particular state, with the former acting as the coordinating agency.

It is recognized that the soils departments of the state experiment stations are best qualified to do the state's part of the work, because of special knowledge of the soils of the state, and because of the fact that all soil fertility investigations should be closely correlated with soil classification.

For these reasons, the federal Bureau of Chemistry and Soils and the state experiment stations have in most cases entered into cooperative agreements for carrying on soil survey work. In such agreements the expenses are divided equally between the two cooperating agencies.

The soil survey is of value to the individual farmer because it classifies the agricultural and the nonagricultural land, and indicates soils which are best adapted to special crops and areas best suited to intensive cropping systems. It is of particular value to farmers who are seeking new locations and to city folks who are interested in buying farm land, and in general, for locating suburban developments or in seeking land suitable for parks or golf courses.

State agricultural experiment stations utilize the information in the reports to aid them in the locating of outlying experimental fields, agricultural high schools, and colleges and the county agents make extensive use of the soil maps and reports in dealing with cropping systems and soil management problems. Road engineers and factory managers use the maps in locating roads, road building materials, and deposits of clay and other raw materials.

Other unusual but very important uses which are being made of the soil survey reports are in connection with public health and sanitary surveys made by large life insurance companies, and by banks in connection with loans made on farm lands.

The actual average cost, including both federal and state expenses, is only a fraction over two cents per acre. It is doubtful if there is any other line of public work of such great economic value that can be done at so low a cost to the taxpayer.

Since 1899 over 1,100 areas have been surveyed, aggregating over 800,000,000 acres. Much scientific data have been collected. The characteristics of soils have been determined and evaluated, their course of development traced, and fundamental facts have been determined to make possible a scientific classification of the soils of the United States and thus broaden the foundation of a rational soil science.

With the reorganization of the work incident to the setting up of the new Bureau of Chemistry and Soils it is planned to extend and more fully coordinate the work of the soil survey with the other activities of the federal government and with those of the state colleges and experiment stations.

The soil survey has been engaged in the determination of soil characteristics, in the isolation of soil types, and in mapping their distribution for many years. The work has been distributed widely over the country. Through this wide distribution important knowledge regarding the characteristics of the soils in all parts of the country has been obtained. Very little work has been done, however, in the evaluation of the soils that have been mapped. We know the characteristics of these soils. We do not yet know, except such knowledge as has been gained incidentally, the value of these types in terms of agriculture. One of the necessary lines of work in order to determine this is to carry on studies in various parts of the country organized for the purpose of obtaining this evaluation data. Study should be carried on in each of the great soil regions of the United States. This should be carried on for a number of years, long enough to be able through the accumulated data to eliminate the accidental and temporary conditions controlling crop yields and determine the effect of the soil factor. This work should be begun now.

THE FERTILIZER RESEARCH PROGRAM

As you well know we already have a number of different agencies engaged in fertilizer research. Federal funds for this work are expended by government agencies at Washington and the various sub-

stations throughout the United States. The state agricultural experiment stations, while deriving much of their support from state appropriations, have their funds for research programs substantially augmented by grants made to the states under the terms of the Hatch, Adams, and Purnell Acts.

The comprehensive program of fertilizer research as outlined before the Second National Fertilizer Conference by Dr. Oswald Schreiner[3] a few weeks ago, fits into the program for soil research which I have in mind. As he points out, such a program must be based upon a knowledge of the soils of the country as a whole. It is necessary, therefore, to recognize the different soil regions of the United States and to make use of the modern system of soil classification into large and related groups, thus basing our fertility studies on the foundation laid by a soil survey of our national domain. Field results obtained by research conducted on well-defined soil types may be applied in practice to similar soils under like climatic conditions. In order to obtain the desired broad interpretation of results, it becomes necessary to have some nationalizing influence capable of making these broader interpretations, but leaving the states free to make local applications of fundamental principles.

As pointed out by Dr. Schreiner, the problem of organizing a national fertilizer research program is not an easy one and any attempt in this direction must take into consideration the numerous agencies already in the field. To secure effective administration he would divide the United States into nine regions on the basis of soil relationships, climate, and agricultural practice. Each of these regions would be in charge of a regional director of research, who would cooperate with the agronomist in each state in working out a state program. Under this plan the state agronomist would receive a part of his salary from the federal government so that he might travel on government funds if necessary to neighboring states and to regional meetings. The work of the regional director would be supported by a soil specialist in each state in his region, while the states would be expected to furnish assistant agronomists to carry out the state's part of the program. These men would formulate and put into execution field investigations at a number of different places in each state. The county agents of the extension service would cooperate in the selection of the experimental fields and would be expected to take the work to the farmers by arranging local meetings and inducing the farmers to visit the experimental fields.

[3]Address given at West Baden, Ind., Sept. 5, 1928, and printed in *The Fertilizer Review* for October 1928.

Of necessity this fertilizer research program would be developed gradually by inaugurating the work in the East where fertilizers are used most intensively, and gradually extending into the West as funds become available.

SOIL EROSION RESEARCH PROGRAM

Recent discussions of national problems in connection with flood control measures has served to emphasize the fact that soil erosion constitutes a serious menace and is responsible for tremendous losses of soil materials. Although several federal and state agencies have been giving some attention to this question, as yet there is very little fundamental data available as to the erosivity of the different soil types. Up to the present, only three out of a large number of important soil types have had measured their rate of loss of surface material under erosion. In the main we agronomists have devoted our attention almost entirely to the consideration of ways and means of checking losses of plant food material through leaching and the removal of crops, overlooking the factor of erosion almost completely. In a number of the southern states the practice of terracing is rapidly gaining favor among farmers, but the extension of this practice is being retarded by lack of knowledge regarding the fundamental factors concerned in the control of erosion. It is known that certain soils occupying slopes of the same grade erode at very different rates and that types of terraces that have proved effective under one set of conditions are entirely ineffective when applied to a different soil having the same slope and under the same conditions as to rainfall. It is necessary to know at what degree of slope cultivation should cease on the different soil types, where grass should be seeded, or where re-forestation should be recommended. A great amount of fundamental information of this character is needed before engineers can devise effective terracing systems and deal intelligently with problems of river and flood control.

For a number of years the Missouri Experiment Station has been doing pioneer work in the study of soil erosion, and more recently Texas and other southern States have attacked the problem at their field stations. Different agencies of the federal government have also been collecting data upon which to build a program of soil conservation. The time is at hand when state and federal agencies should join forces in a cooperative nation-wide effort to establish fundamental principles and promulgate practices that will check the enormous losses occasioned by unrestricted soil erosion. The situation with regard to soil erosion may be summarized as follows:

I. Losses from Erosion.
   1. Removal of topsoil.
   2. Removal of plant-food material.
   3. Over-wash onto lowlands—usually harmful; sometimes beneficial.
   4. Flood damage increased by silting of streams.
   5. Silting up of reservoirs.

II. Factors Affecting Soil Erosion.
   1. Soil type.
   2. Slope of surface.
   3. Rainfall—amount and distribution.
   4. Cultural methods.

III. What Has Been Done.
   1. Reconnoissance survey of soil types as to ease of erosion.
   2. Run-off and wash-off measurements at stations in Missouri and Texas.
   3. Terracing programs of the extension service in some states.
   4. Study of systems of terracing by the Office of Public Roads and by state experiment stations.
   5. Range management erosion studies by the Forestry Service.

IV. What Needs To Be Done.
   1. Fundamental study of physical and chemical characteristics of soil types subject to severe erosion.
   2. Study of effectiveness of different systems of terraces when applied to different soil types and systems of management.
   3. Study of the effectiveness of different physical and chemical treatments applied to terraces.
   4. Study of cropping systems in relation to erosion control.

V. How the Problem Should be Attacked.
   1. Representative samples from easily eroded soil types are being collected and their physical and chemical properties compared with those of soils that are known to resist erosion.
   2. Field stations should be established in different regions for the study of rates of erosion, and the effectiveness of different systems of terracing under different cropping systems, variations in slope, rainfall, and soil types. These field stations should be under the joint control of federal and state agencies. This arrangement would permit of the correction of the results by the federal agencies and the application of results to restricted regions by the state agencies.

SOIL ORGANIC MATTER SURVEY

The recent development of efficient methods for securing an unlimited supply of nitrogen from the air for fertilizer purposes has done much to remove the shadow cast by Sir Wm. Crooke's direful prediction that mankind would in the distant future be faced with the possibility of nitrogen starvation. Under our present economic conditions, however, agriculture must continue to depend in a large measure upon the organic matter of the soil to supply the nitrogen and the necessary conditions within the soil favorable to plant growth. So long as these conditions prevail soil organic matter will continue to be synonymous with soil fertility.

A recent estimate places the annual loss of nitrogen from the soils of the United States at 9,000,000 tons, with only 260,000 tons returned to the soil in the form of commercial fertilizer. It is estimated that under our present cropping system legumes contribute as much as 1,750,000 tons of nitrogen toward making up this deficiency. The growing of legumes to supply nitrogen and to keep up the organic matter supply of the soil is a problem of national importance and worthy of the attention of our research workers in the field of agronomy.

The general acceptance of soil and seed inoculation with nitrogen-fixing bacteria as a basis for growing such soil-improving crops as clovers, alfalfa, and soybeans has stimulated the production of cultures for this purpose by many public and private agencies. The Department of Agriculture is encouraging such development in every way possible, while strengthening its inspection of the cultures offered for sale to the farmer.

Forty-eight institutions are now offering bacterial cultures for sale. In general, the quality of the cultures has been good, but certain brands failed to show the merits claimed for them. Steps have been taken to protect the farmer as far as possible from worthless products.

It is expected that studies now in progress will reveal means whereby some of the little-known members of the invisible soil population may be made more efficient by selection, by adjustment of crops, or by addition of fertilizers and soil amendments, but for the present the nodule bacteria of legumes remain the only ones satisfactorily utilized in trade.

The practical successes achieved in the handling of legume bacteria encourage the hope that similar investigations of other groups of bacteria may bring other elements of the complex population of the soil to the service of the farmer. To that end biological studies of a

series of soils varying widely in texture and acidity have been started in Department laboratories with the expectation that the results will be of great fundamental importance, not only to experiment station workers, but to manufacturers of commercial legume cultures as well.

In view of the great practical importance of green manuring in the maintenance of soil fertility and the demand for more exact information upon which to work out a program, the federal Department has recently established a committee to cooperate with the state experiment stations in making a concerted attack upon the whole subject. This action was taken with the view of eliminating unnecessary duplication of effort and the adoption of proceedings best calculated to secure quick and accurate results. Under the plan adopted by this committee it is proposed to take an inventory of our soil organic matter resources and to make a thorough study of the fundamental principles underlying the practice of green manuring with respect to rate of decay of organic matter in the soil, the amount of nitrogen supplied, and the utilization of the intermediate products of decomposition. The plan contemplates a coordination of effort on the part of all workers in this field, including the different bureaus at Washington, and all of the state experiment stations interested in the subject, thus eliminating duplication and at the same time insuring the application of the results of the research most widely and promptly.

DIVERSION OR UTILIZATION OF SURPLUS PRODUCTS

As a part of the national program of soil research, as outlined, would be a decrease in the acreage now under cultivation by the elimination of marginal and submarginal lands. The increased total production through increased acre yields may lead to economic disaster unless some consideration is given to the profitable diversion of possible surpluses and to the better utilization of farm wastes which are potentially available for industrial purposes.

In the formulation of plans for the profitable diversion of surplus products the agronomist must cooperate with the economist in the working out of methods. The disposition of the enormous amount of farm residue, such as corn stalks, straw, and other roughage, a major portion of which is potentially available for industrial purposes, should be given more than passing attention. Future developments will determine the extent to which this residue should be converted into materials which may find industrial application in preference to being returned to the soil for the purpose of keeping up the organic matter content and supplying food and energy for the microbiological population of the soil.

Offers of ready cash may tempt the farmer to sell waste material for utilization in industry, to the detriment of his soil. Such products as straw may be burned and the ashes returned to the soil; they may be converted into manure by means of bacterial fermentation; they may be spread on the land and plowed under to supply organic matter. If sold for commercial utilization they might be converted into gas, acetic acid, methanol, paper, or other manufactured products. In some cases farmers have, through their cooperative societies, invaded the commercial field, to provide outlets for their waste and surplus products. An example of this development is found in the California Fruit Growers In addition to the grading, packing, and marketing of their products they are now converting former waste products into valuable products through the manufacture of citric acid, orange and lemon oils, and pectin from culls and other citrus waste Shifting conditions may make possible the utilization of marginal and submarginal land for the production of raw materials. As far back as 1876 chemists in the Department of Agriculture called attention to the high tannin content of the sumac which may be as high as 25% in the dried leaves. Ravages of the chestnut blight may make it economically feasible and desirable to devote large areas of practically worthless land to the production of sumac which is known to make good growth under exceedingly adverse soil conditions.

Thus the changing economic condition and the development of chemical and bacterial processes may serve to make the waste products of today important articles of commerce tomorrow, and to emphasize the fact that the principal business of the farm is the manufacture of useful organic materials from Nature's raw materials stored in the soil and present in the atmosphere.

A BIOMETRICAL ANALYSIS OF THE EFFECT OF ENVIRONMENT ON A PURE LINE OF OATS[1]

Alfred Atkinson and H. H. Love[2]

INTRODUCTION

This experiment was undertaken at a time when there was considerable discussion as to the possible effect of different environmental conditions on the permanency of a pure line. The results of Johannsen (1)[3] had pointed out the importance of pure lines and their permanency under local conditions. It was the thought in planning the present experiment to study a pure line under different conditions. With this in mind, a cooperative experiment was arranged by the authors whereby the oats were to be grown in Montana and New York for several years. The crops were grown on the grounds of the agricultural experiment stations at Bozeman, Montana, and at Ithaca, New York. The authors express their appreciation to the officials of these stations, and to all others whose help made this experiment possible. In connection with the Montana work it is desired to mention especially Professors W. D. Tallman and L. F. Gieseker and Mr. Ernest Morris. Thanks are also due to W. T. Craig and Frances Feehan of the Plant Breeding Department of the College of Agriculture at Ithaca, N. Y.

MATERIAL AND METHODS

Oats, as stated above, was the crop chosen for the experiment, since both authors at that time were interested in this crop, and also because it is one that grows well in both states. A pure line of Sixty Day oats, which had been grown in New York previous to this experiment, was selected for the investigation.

The plan of the experiment was to grow a lot of plants in each place and make a study of the individual plants from year to year. The seed was sown with sufficient space so that individual plants could be harvested. It was also planned that after two or three years an exchange of seed was to be effected, thus making it possible to determine whether the different environments were producing any heritable changes in the plants.

[1]Joint contribution. Published as a paper from the Montana Agricultural Experiment Station, Bozeman, Mont., and as paper No. 158, Department of Plant Breeding, Cornell University, Ithaca, N. Y. Received for publication August 20, 1928.

[2]President, Montana State College of Agriculture, and Professor of Plant Breeding, Cornell University, respectively.

[3]Reference by number is to "Literature Cited," p. 1291.

Beginning with 1915, seed from both Montana and New York was sent to the other state to be grown in comparison with the seed produced in that state. In each year following seed from the previous crop was sent to Montana or New York for growing a new lot of plants. Hereinafter the seed produced at one station will be referred to as "home-grown," while that brought in in the exchange of seed will be designated "imported." Throughout the report Ithaca, N. Y., and Bozeman, Mont., will be referred to as "New York" and "Montana," respectively.

It was felt that a study of the variation and correlation of characters would be the best method to use to determine any changes that might occur. Consequently, data were taken on a number of characters and these were used in making a biometrical analysis and comparison.

This experiment continued for eight years, from 1912 to 1919, and demonstrates the possibility of conducting cooperative experiments where different investigators are interested in the same problem.

SOIL

The soil on which the oat plants were grown in New York belongs to the Chenango gravelly silt loam type. The particular field used was a small isolated tract somewhat more loamy in character than the main body of this type of soil.

The Chenango gravelly silt loam soils result from the accumulation of materials deposited in bodies of water, giving rise to deltas. The surface soil, about 10 inches in depth, consists of yellowish-brown, friable, silt or fine loam. The upper subsoil, to a depth of about 16 inches, is grayish, gritty, silt loam, somewhat heavier than the surface soil, while below the upper subsoil, to a depth of 36 inches, the subsoil consists of pebbly or gravelly, coarse, silt loam. The material throughout this soil is low in lime.

TABLE 1.—*Chemical composition of the surface foot of Chenango gravelly silt loam and Bozeman silt loam.*

Constituents determined	Chenango gravelly silt loam (New York) %	Bozeman silt loam (Montana) %
Organic matter	7.55	5.44
Nitrogen	0.18	0.17
Phosphoric anhydride	0.31	0.29
Potassium oxide	0.32	0.60
Calcium oxide	0.28	1.16
Magnesium oxide	0.70	1.15
Sulfur trioxide	0.06	0.11

The soils used in Montana are classified as Bozeman silt loam, and were formed by sedimentation. The surface soil to a depth of 1 foot consists of dark, somewhat sticky, silty loam of compact quality, but easy to cultivate when in the proper condition. The subsoil consists of heavy, silty, clay loam to a depth of 3 feet. The soils both in New York and Montana are well suited to the production of general field crops. A statement of the chemical composition of the surface foot of the soil at each station is given in Table 1.

In connection with Table 1, attention is called to the higher lime content in the Bozeman soil. The effect of this would be to bring about greater activity in the nitrogen products, resulting in higher productivity

CLIMATE

To make convenient a comparison of the climatic conditions prevailing at Ithaca and at Bozeman during the period of the experiment, tables of weather data are given. These show the summer temperatures, total degrees of growing temperature during the crop season, length of day from sunrise to sunset, hours of sunshine during the growing season, and the interrelation of these climatic factors. No comparison of precipitation is made, since the crop in Montana was grown under irrigation.

TEMPERATURES

Table 2 shows the summer temperatures by weeks for the years 1912 to 1919 in New York and in Montana. The data cover the growing seasons at the two stations, and show the New York season to be somewhat shorter.

A study of the table shows uniformly higher temperatures in New York than in Montana, and this difference is especially marked during June and July. Such high temperatures at the time the crop is maturing hasten the ripening process and account for the shorter growing season in the warmer sections of the country. This point will be brought out more fully in the discussion of the crop data.

GROWING TEMPERATURES

Since growing processes in field crops are very slight at temperatures below 40 degrees, the total number of degrees of temperature above 40 was determined for the growing season at each station. The mean daily temperature as reported for each day was used and the number of degrees above 40 was taken as the growing temperature. That is, for readings of 50 degrees we have 10 degrees of growing temperature, while for a reading of 35 degrees we have —5 degrees of growing temperature. These daily totals were summarized and are reported by months for 1914, 1915, 1916, 1917, and 1919 in Table 3.

TABLE 2.—*Average weekly temperature during the summer season for 1912 to 1919 at New York and Montana.*

Dates	1912 New York	1912 Montana	1913 New York	1913 Montana	1914 New York	1914 Montana	1915 New York	1915 Montana
Apr. 1–7	42	41.0	43	34.3	34	38.4	38	44.3
8–14	39	42.0	43	47.1	38	41.2	50	48.6
15–21	49	37.0	46	47.8	48	42.1	49	50.8
22–28	48	40.0	62	43.1	48	40.3	67	48.8
29–May 5	50	39.0	61	35.5	51	44.4	51	41.9
May 6–12	60	47.0	49	48.9	57	45.3	57	50.1
13–19	53	53.0	54	40.1	54	52.3	47	44.6
20–26	62	48.0	54	54.7	67	52.5	53	47.2
27–June 2	63	53.0	57	62.3	65	60.1	55	52.3
June 3–9	59	55.0	57	60.4	65	50.7	62	47.9
10–16	60	52.0	66	55.3	66	54.7	66	49.3
17–23	62	62.0	65	60.2	62	58.2	64	54.3
24–30	70	66.0	74	54.9	70	55.7	63	55.1
July 1–7	75	55.0	74	60.9	67	63.0	67	55.5
8–14	78	58.0	66	57.6	75	65.6	68	56.7
15–21	68	60.0	68	64.9	71	63.2	70	55.5
22–28	64	65.0	71	59.4	70	66.4	69	62.3
29–Aug. 4	—	62.0	—	61.4	—	69.5	—	59.8
Aug. 5–11	—	61.0	—	56.9	—	62.0	—	65.7
12–18	—	55.0	—	60.3	—	64.3	—	64.4
19–25	—	61.0	—	67.6	—	57.1	—	61.2
26–Sept. 1	—	57.0	—	67.4	—	58.4	—	65.1
Sept. 2–8	—	52.0	—	63.6	—	60.1	—	53.4
9–15	—	46.0	—	55.7	—	45.6	—	41.9
16–22	—	45.0	—	53.0	—	51.6	—	53.3
23–29	—	41.0	—	44.0	—	56.5	—	45.0

		1916		1917		1918		1919	
		New York	Montana	New York	Montana	New York	Montana	New York	Montana
Apr.	1–7	41	36.1	44	31.4	46	26.4	43	38.4
	8–14	40	42.4	35	37.9	38	45.0	48	36.8
	15–21	50	39.6	51	36.4	48	35.5	44	45.9
	22–28	48	46.5	45	36.9	48	36.7	42	50.7
	29–May 5	57	44.6	43	35.5	54	52.6	52	41.4
May	6–12	56	41.0	45	49.3	61	41.6	47	44.6
	13–19	53	41.8	51	54.1	64	47.6	57	51.3
	20–26	60	40.1	49	47.2	63	41.3	60	63.4
	27–June 2	63	46.9	57	44.0	72	44.2	68	53.4
June	3–9	61	50.9	63	50.7	63	62.1	74	56.6
	10–16	61	53.3	62	52.0	59	70.3	74	59.9
	17–23	58	51.6	65	59.7	56	67.2	70	71.7
	24–30	66	58.9	66	60.2	68	58.1	65	70.6
July	1–7	67	62.5	68	64.7	63	61.1	72	67.7
	8–14	76	66.7	65	69.6	62	64.3	67	71.4
	15–21	77	63.2	72	71.2	72	64.9	71	68.4
	22–28	77	65.1	76	73.2	79	57.8	75	72.3
	29–Aug. 4	—	65.8	—	62.8	—	69.0	—	66.8
Aug.	5–11	—	59.7	—	61.3	—	58.1	—	64.1
	12–18	—	60.1	—	66.7	—	59.8	—	65.9
	19–25	—	57.8	—	64.5	—	58.7	—	68.9
	26–Sept. 1	—	64.1	—	58.9	—	59.6	—	65.1
Sept.	2–8	—	57.9	—	61.3	—	50.9	—	56.4
	9–15	—	45.9	—	56.8	—	52.9	—	58.7
	16–22	—	56.5	—	59.7	—	58.9	—	56.0
	23–29	—	47.4	—	49.7	—	50.6	—	47.5

TABLE 3.—*Total degrees of temperature above 40 during the growing season for 1914, 1915, 1916, 1917, and 1919 at New York and Montana.*

Year	Planting and harvesting dates		Month	Degrees of temperature above 40	
	New York	Montana		New York	Montana
1914	May 7–Aug. 6	May 14–Aug. 16	May	523	255
			June	764	457
			July	935	770
			August	131	379
			Total	2,353	1,861
1915	Apr. 19–July 22	May 8–Aug. 24	April	271	—
			May	359	216
			June	711	334
			July	595	529
			August	—	551
			Total	1,936	1,630
1916	May 1–July 29	May 13–Aug. 29	May	549	44
			June	641	386
			July	959	747
			August	—	567
			Total	2,149	1,744
1917	May 2–Aug. 3	May 6–Aug. 24	May	252	223
			June	714	446
			July	975	887
			August	83	546
			Total	2,024	2,102
1919	Apr. 15–July 14	May 7–July 29	April	53	—
			May	514	346
			June	928	700
			July	382	831
			Total	1,877	1,877
			Grand total	10,339	9,214

Examination of Table 3 shows a considerably greater number of degrees of growing temperature in New York than in Montana for 1914, 1915, and 1916, and practically the same number at each place for 1917 and 1919. For the entire growing periods of the five years there were 1,125, or 12.2%, more degrees of growing temperature in New York than in Montana. This further emphasizes the point of earlier ripening which was referred to in the discussion of Table 2.

LENGTH OF DAY

Table 4 presents data showing the number of hours of daylight, by months, for the growing seasons in New York and in Montana

for 1914, 1915, and 1916. These data give the total number of hours between sunrise and sunset at the two stations for each month of the growing season in the years reported.

Examination of Table 4 shows a total of 4,068.02 hours of daylight in New York and 4,706.61 hours in Montana for the growing seasons of these three years. There was a total of 638.59, or 15.7%, hours more of daylight in Montana than in New York, due entirely to the more northerly location of the western state. This increased amount of daylight during the growing season favors heavier growth.

HOURS OF SUNSHINE

Table 4 also shows the number of hours of sunshine and the percentage of daylight hours having sunshine for the growing seasons of 1914, 1915, and 1916. The total hours of sunshine for the growing seasons for the three years was 2,059.0 in New York and 3,119.9 in Montana. This total is greater by 1,060.9, or 51.5%, in Montana than in New York.

INTERRELATION OF DAYLIGHT HOURS, SUNSHINE, AND GROWING TEMPERATURE

Since the number of hours of daylight and sunshine is higher and the number of degrees of growing temperature is lower in Montana than in New York, these factors have been interrelated in an attempt to measure the various climatic factors that influence crop growth. The percentage of daylight hours having sunshine was multiplied by the number of degrees of growing temperature for each month of the growing period in 1914, 1915, and 1916, giving a daylight-sunshine-growing temperature-factor for each month. This will be found in the last two columns of Table 4.

It will be observed that the total of these interrelated factors for the three growing seasons is 3,288.86 in New York and 3,745.66 in Montana, an increase in Montana of 456.80, or 13.9%. The heavier yields, taller plants, and generally larger kernels obtained in Montana are partly due to the more favorable conditions during the growing season.

COMPARISON OF VARIATION CONSTANTS

Certain measurements were taken to determine the effect of the different environments on the growth and development of the plants. These data were used for the study of the variation and correlation constants.

The characters studied and measured on the crop at both stations were as follows: Number of culms per plant, average length of culm,

TABLE 4.—*Length of day, hours of sunshine, degrees of growing temperature, and interrelation of these factors for 1914, 1915, and 1916 at New York and Montana.*

Planting and harvesting dates		Month	Hours sunrise to sunset		Hours of sunshine		Percentage daylight hours having sunshine		Total degrees temperature above 40		Percentage of daylight hours having sunshine multiplied by number of degrees above 40	
New York	Montana		New York	Montana	New York	Montana	New York	Montana	New York	Montana	New York	Montana
						1914						
May 7–Aug. 6	May 14–Aug. 16	May	366.92	273.97	245.8	202.2	67.0	73.8	523	255	350.41	188.19
		June	455.37	470.80	301 2	307.5	66.1	65.3	764	457	505.00	298.42
		July	461.35	475.23	230.2	377.9	49.9	79.5	935	770	466.56	612.15
		August	71.73	217.30	46.4	194.4	64.7	89.5	131	379	84.76	339.20
		Total	1,355.37	1,437.30	823.6	1,082.0	—	—	2,353	1,861	1,406.73	1,437.96
						1915						
April 19–July 22	May 8–Aug. 24	April	165.27	—	95.5	—	57.8	—	271	—	156.64	—
		May	451.78	362.60	187.7	186.4	41.5	51.4	359	216	148.98	111.02
		June	455.37	470.80	273.6	285.2	60.1	60.6	711	334	427.31	202.40
		July	315.23	475.23	128.5	313.8	40.8	66.0	595	529	242.76	349.14
		August	—	328.87	—	266.8	—	81.1	—	551	—	446.86
		Total	1,387.65	1,637.50	685.3	1,052.2	—	—	1,936	1,630	975.69	1,109.42
						1916						
May 1–July 29	May 13–Aug. 29	May	451.78	288.85	189.2	88.6	41.9	30.7	549	44	230.03	13.51
		June	455.37	470.80	171.0	244.3	37.6	51.9	641	386	241.02	200.33
		July	417.85	475.23	189.9	362.5	45.4	76.3	959	747	435.39	569.96
		August	—	396.93	—	290.3	—	73.1	—	567	—	414.48
		Total	1,325.00	1,631.81	550.1	985.7	—	—	2,149	1,744	906.44	1,198.28
		Grand total	4,068.02	4,706.61	2,059.0	3,119.9	—	—	6,438	5,235	3,288.86	3,745.66

average length of head, average number of kernels per culm, total weight of kernels per plant, average weight of kernels per culm, and average weight of kernel.

NUMBER OF CULMS PER PLANT

The means, standard deviations, and coefficients of variability, with their probable errors, for number of culms per plant are given in Table 5. There is considerable difference in the number of culms on the plants grown in Montana as compared with those grown in New York. For example, in 1912, the mean for the New York-grown plants is $7.270 \pm .063$, while for the Montana-grown plants it is $13.436 \pm .100$. In other words, in that year nearly twice as many culms per plant were produced in Montana as in New York.

The mean number of culms for the entire period of the test is much less for the plants grown in New York than for those grown in Montana. As a matter of fact, the mean number for New York has a tendency to decrease throughout the test. This might be taken as an indication of a loss of vigor, or running out, if it were not for the fact that other data to be considered later do not support this supposition. The principal reason for this decrease is that the garden used for the experiment had been in alfalfa for a number of years and the soil was quite fertile at the beginning of the test, but this state of fertility was not maintained due to lack of requisite fertilizer.

The standard deviation is smaller for the New York-grown plants, except in 1915, when it is practically the same for both tests. Under ordinary circumstances with the same material one expects larger standard deviations to be associated with larger means.

While the standard deviations are generally larger for the Montana-grown material, the coefficients of variability are consistently larger for the New York-grown plants. There is somewhat greater variation as measured by the coefficient of variability, although this difference is not consistent.

As stated earlier, after the experiment had been under way for three years an exchange of seed was effected. That is, beginning with 1915, seed grown in New York the previous year was sent to Montana for testing and, likewise, seed produced in Montana in 1914 was grown in New York in 1915. Thereafter there were two tests grown at each station, one from the seed produced at that station the previous year and one from seed produced the previous year in the other locality. This made it possible to determine what effect environment may have had in producing heritable changes or in any way affecting the variability.

The means, standard deviations, and coefficients of variability for these data on number of culms are given in Table 5. The comparison of the means is also shown graphically in Fig. 1.

The results indicate that the plants from the home-grown and imported seed at each locality are very similar so far as number of culms is concerned. In 1915 the average number of culms for the plants grown in New York from home-grown seed is 5.287 ± .076, while for the plants grown in Montana from home-grown seed it is 7.478 ± .068. For the same year the mean number of culms for

TABLE 5.—*Means, standard deviations, and coefficients of variability for number of culms per plant.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
		Means		
1912	7.270±.063		13.436±.100	
1913	8.637±.086		15.761±.148	
1914	7.300±.074		11.401±.078	
1915	5.287±.076	5.277±.076	7.478±.068	7.933±.076
1916	3.790±.041	3.895±.039	14.456±.140	16.120±.157
1917	3.140±.035	3.382±.040	13.325±.131	12.206±.096
1918	3.212±.037	3.335±.036	12.770±.093	12.996±.081
1919	2.895±.032	3.002±.034	12.364±.119	12.642±.143
		Standard Deviations		
1912	1.875±.045		3.328±.071	
1913	2.565±.061		4.889±.104	
1914	2.197±.052		2.710±.055	
1915	2.253±.054	2.244±.054	2.168±.048	2.680±.054
1916	1.202±.029	1.168±.028	4.496±.099	4.900±.109
1917	1.030±.025	1.178±.028	3.658±.093	3.192±.068
1918	1.101±.026	1.074±.026	3.066±.066	2.690±.057
1919	0.959±.023	0.999±.024	3.882±.084	4.320±.101
		Coefficients of Variability		
1912	25.79± .65		24.77±.56	
1913	29.70± .77		31.02±.72	
1914	30.10± .78		23.77±.51	
1915	42.61±1.19	42.52±1.18	28.99±.70	33.78±.82
1916	31.72± .83	29.99± .78	31.10±.75	30.40±.74
1917	32.80± .86	34.83± .93	27.45±.75	26.15±.59
1918	34.28± .91	32.20± .84	24.01±.54	20.70±.46
1919	33.13± .87	33.28± .88	31.40±.74	34.17±.89

the plants from imported seed grown in New York is 5.277 ± .076 and for the plants from imported seed grown in Montana it is 7.933 ± .076. It is apparent that the source of seed does not affect the type of plant, but the environment under which the plants are developed does have an influence.

The comparison of the means for the other years shows a greater difference in the number of culms between the New York and

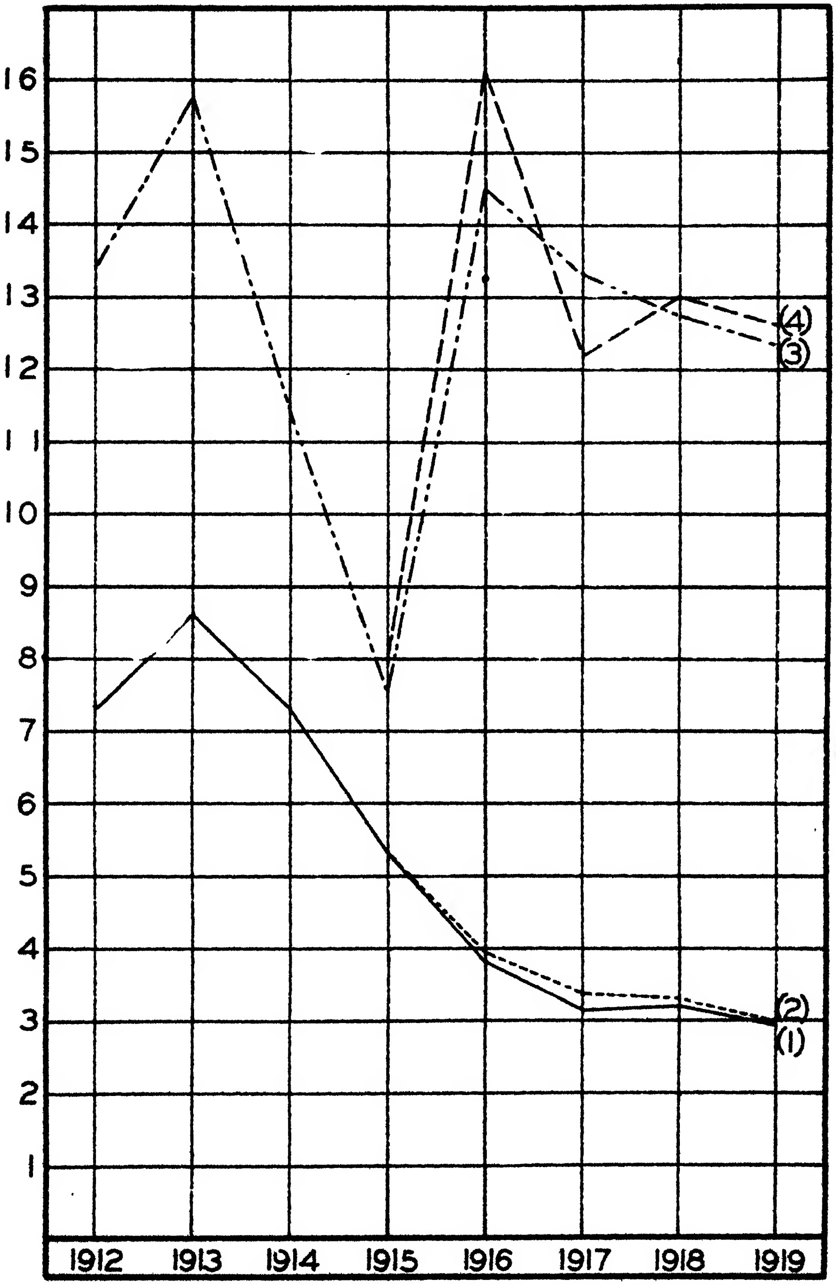

FIG. 1.—Average number of culms per plant for the New York plants from home-grown and imported seed and the Montana plants from home-grown and imported seed. (1) New York home-grown; (2) New York imported; (3) Montana home-grown; (4) Montana imported.

Montana-grown plants, yet when comparisons are made between the plants grown at each station from seed from both sources the mean number of culms agrees very closely. The fact that when New York seed is grown in Montana the means are very similar to those from home-grown seed in Montana indicates that the strain is not running out, as might be suggested on account of the gradual decrease in the means in New York. There are some variations, notably the results in Montana in 1916, where the mean for the plants from home grown seed is 14.456 ± .146 and the mean for the plants from imported seed is 16.120 ± .157. Although the difference between these means is significant, the difference is much smaller than that between the means from the plants from the New York seed grown in the two localities.

The standard deviations and coefficients of variability show in general a similar close agreement. There are some variations as, for example, in the coefficients of variability for the Montana data in 1915. Here the coefficient for the plants from home-grown seed is 28.99 ± .70, while the coefficient for the plants from imported seed is 33.78 ± .82. This difference might be expected, as slight deviations in the means and standard deviations would tend to produce such a result.

AVERAGE LENGTH OF CULM

The length of each culm per plant was taken in centimeters, and the average length per culm used for a comparison of the plants grown in the two localities. The constants for this character are given in Table 6.

The comparisons show that in certain years the plants grew much taller in Montana than in New York. This is especially true for the years 1912, 1913, and 1914. For the next three years, however, the New York-grown plants were taller than Montana-grown plants, while for the years 1918 and 1919 the Montana-grown plants were slightly taller. All together, the Montana-grown plants were taller for five years out of the eight.

There was considerable variation in the results for the different years, both at New York and Montana. For example, the range in height for the New York-grown plants is from 60.410 ± .193 to 91.875 ± .306 cm, or a difference of 31.465 ± .362. For the Montana-grown plants the range is from 62.674 ± .179 to 106.584 ± .324 cm, or a difference of 43.910 ± .370, giving a greater range for the Montana-grown plants.

The standard deviations for the plants grown at the two places do not show any consistent tendency. For the first three years the

TABLE 6.—*Means, standard deviations, and coefficients of variability for average length of culm in centimeters.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
		Means		
1912	77.875±.173		93.924±.193	
1913	69.500±.199		106.584±.324	
1914	68.375±.187		92.223±.259	
1915	88.475±.225	89.550±.204	74.039±.204	72.425±.219
1916	88.725±.304	91.425±.259	84.711±.221	91.173±.208
1917	91.875±.306	93.260±.279	75.836±.303	78.006±.205
1918	87.285±.266	90.975±.274	92.651±.222	90.731±.234
1919	60.410±.193	61.460±.203	62.674±.179	63.234±.201
		Standard Deviations		
1912	5.120±.122		6.390±.136	
1913	5.915±.141		10.719±.229	
1914	5.555±.132		6.579±.184	
1915	6.665±.159	6.045±.144	6.489±.144	7.674±.154
1916	9.005±.215	7.680±.183	7.089±.156	6.510±.146
1917	9.075±.216	8.285±.198	8.475±.215	6.810±.145
1918	7.885±.188	8.135±.194	7.323±.157	7.815±.166
1919	5.730±.137	6 020± 144	5.850±.127	6.069±.142
		Coefficients of Variability		
1912	6.57±.16		6.80±.15	
1913	8.51±.20		10.06±.22	
1914	8.12±.19		7.13±.15	
1915	7.53± 18	6.75±.16	8.76±.20	10.60±.23
1916	10.15±.24	8.40±.20	8.37±.19	7.14±.16
1917	9.88±.24	8.88±.21	11.18±.29	8.73±.19
1918	9.03±.22	8.94±.21	7.90±.17	8.61±.18
1919	9.49±.23	9.79±.24	9.33±.20	9.60±.23

values are higher for the Montana-grown plants, while for the next four years they are higher for the New York-grown plants. The range is greater for the Montana-grown plants, as is shown by the following comparison. The range for the New York-grown plants is from 5.120 ± .122 to 9.075 ± .216 cm, while for the Montana-grown plants it is from 5.850 ± .127 to 10.719 ± .229 cm. The differences are 3.955 ± .248 and 4.869 ± .262 cm, respectively.

The coefficients of variability are, for the most part, rather low for the plants at both localities. There is no consistent relation as they vary from year to year, being higher first for one locality and then for the other.

The comparison figures for the plants grown from imported seed are interesting, especially for the means. The comparison for the means is shown graphically in Fig. 2.

The means for the two lots of plants grown at each station agree rather closely. There is one important exception, for the year 1916 at Montana, where the difference is marked. For the years 1918

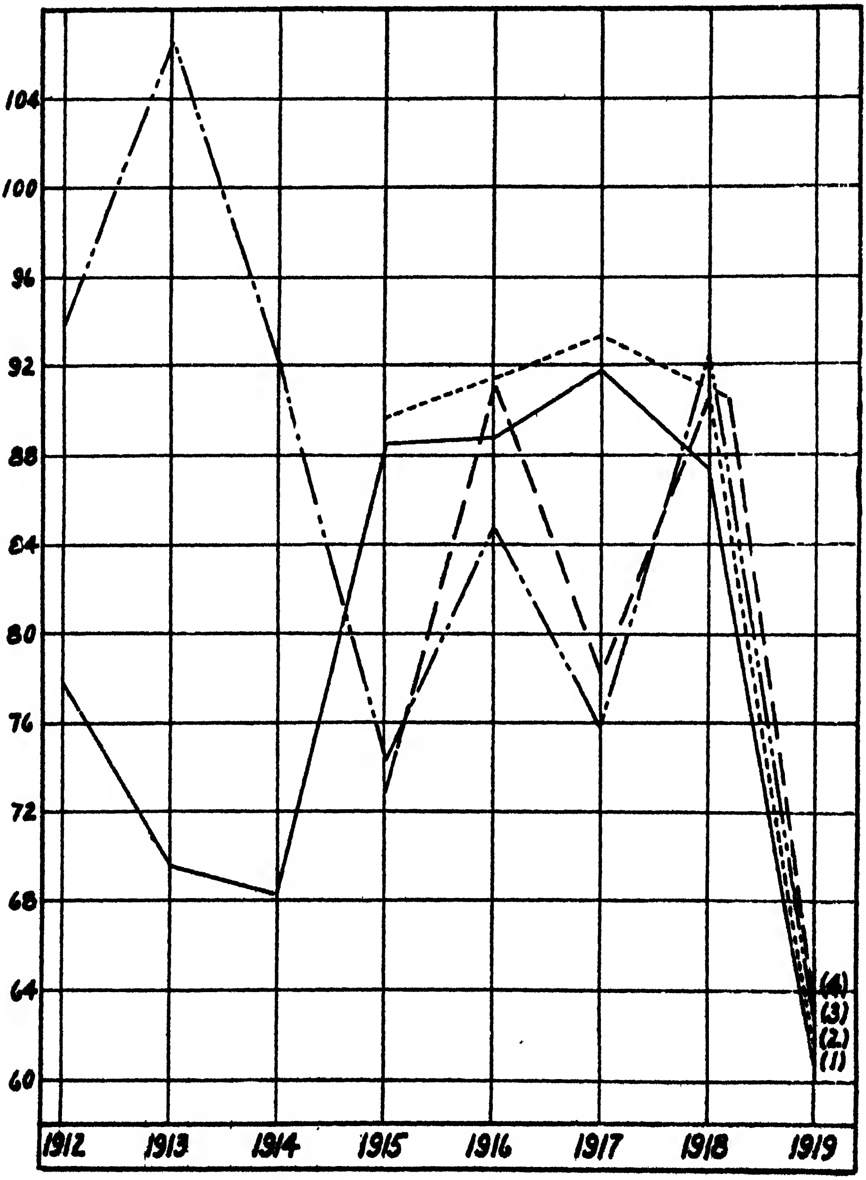

Fig. 2.—Average length of culm for the New York plants from home-grown and imported seed and the Montana plants from home-grown and imported seed. (1) New York home-grown; (2) New York imported; (3) Montana home-grown; (4) Montana imported.

and 1919 it is noted that there is little difference between the means for the Montana-grown and New York-grown plants.

As there is no consistent tendency found for the standard deviations and coefficients of variability, as pointed out above, there is little chance of any consistent comparisons. This is evident from the results as given in the table.

AVERAGE LENGTH OF HEAD

The data for average length of head are given in Table 7.

The average length of head is somewhat greater for the Montana-grown plants than for the New York-grown plants. The yearly figures, however, show that the mean is higher in Montana for four years and that for the other four it is higher in New York.

The standard deviations give a higher average for the New York-grown plants. The average for the New York test is 1.459 ± .012, while for the Montana test it is 1.294 ± .010. The coefficients of

TABLE 7.—*Means, standard deviations, and coefficients of variability for average length of head in centimeters.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
		Means		
1912	18.930±.040		17.352±.036	
1913	16.495±.052		18.719±.043	
1914	14.902±.036		18.464±.035	
1915	16.257±.045	16.250±.041	15.682±.044	15.512±.039
1916	17.450±.062	17.782±.049	17.017±.041	17.842±.038
1917	17 175±.060	17.680±.055	16.799±.052	17.012±.038
1918	16.197±.048	16.567±.046	16.581±.034	16.941±.036
1919	14.300±.050	14.302±.051	15.329±.037	15.462±.043
		Standard Deviations		
1912	1.181±.028		1.203±.026	
1913	1.539±.037		1.439±.031	
1914	1.068±.025		1.224±.025	
1915	1.347±.032	1.213±.029	1.400±.031	1.373±.027
1916	1.850±.044	1.467±.035	1.290±.028	1.206±.027
1917	1.784±.043	1.629±.039	1.450±.037	1.250±.027
1918	1.436±.034	1.358±.032	1.138±.024	1.188±.025
1919	1.470±.035	1.498±.036	1.209±.026	1.309±.031
		Coefficients of Variability		
1912	6.24±.15		6.93±.15	
1913	9.33±.22		7.69±.17	
1914	7.17±.17		6.63±.14	
1915	8.29±.20	7.46±.18	8.93±.20	8.85±.19
1916	10.60±.26	8.25±.20	7.58±.17	6.76±.15
1917	10.39±.25	9.21±.22	8.63±.22	7.35±.16
1918	8.87±.21	8.20±.20	6.86±.15	7.01±.15
1919	10.28±.25	10.47±.25	7.89±.17	8.47±.20

variability also give a higher average for the New York-grown plants, the averages being 8.90 ± .08 and 7.64 ± .06, respectively.

The comparisons between the plants grown from imported seed

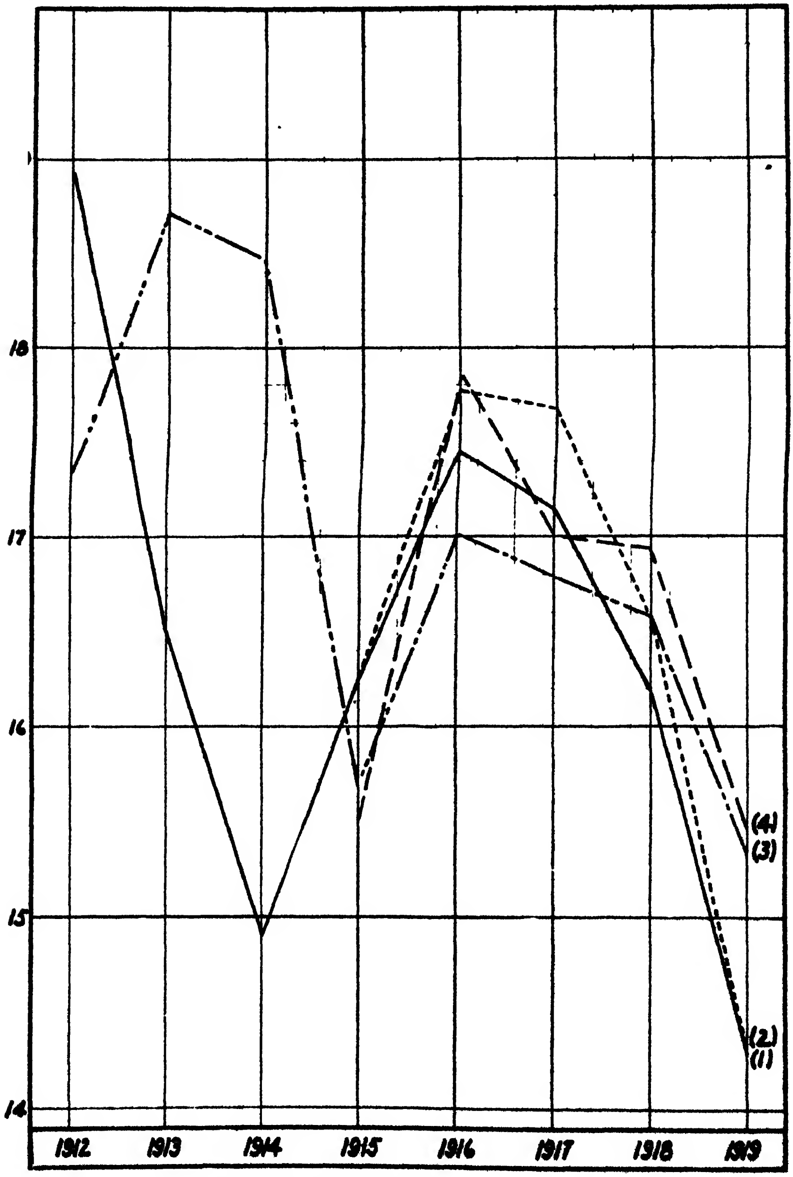

FIG. 3.—Average length of head for the New York plants from home-grown and imported seed and the Montana plants from home-grown and imported seed. (1) New York home-grown; (2) New York imported; (3) Montana home-grown; (4) Montana imported.

are also shown in Table 7, while the means are shown graphically in Fig. 3. The agreement between the two lots grown in New York is very close, with the possible exception of the 1917 crop. Similarly, the plants in the tests in Montana agree closely, with the exception of the 1916 crop.

There is also a very close agreement, for the most part, in the standard deviations. While the coefficients of variability do not agree so closely, they are rather uniformly high or low. A closer agreement is found for the two lots grown at the same place than is found between the lots grown in Montana and in New York.

AVERAGE NUMBER OF KERNELS PER CULM

The total number of kernels per plant were counted and the average number of kernels per culm determined. These data are given in Table 8.

TABLE 8.—*Means, standard deviations, and coefficients of variability for average number of kernels per culm.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
		Means		
1912	90.550±.538		86.360±.440	
1913	45.500±.476		99.018±.613	
1914	52.950±.369		95.456±.759	
1915	52.320±.422	53.100±.404	67.531±.452	65.385±.420
1916	60.520±.616	66.170±.548	72.284±.388	76.932±.421
1917	61.900±.648	68.070±.591	77.840±.509	76.597±.440
1918	59.650±.521	63.750±.573	66.410±.377	65.880±.399
1919	41.050±.448	42.000±.506	57.585±.363	57.160±.444
		Standard Deviations		
1912	15.960±.381		14.584±.311	
1913	14.130±.337		20.296±.434	
1914	10.950±.261		16.350±.334	
1915	12.520±.299	11.970±.285	14.400±.320	14.725±.296
1916	18.270±.436	16.240±.387	12.450±.275	13.350±.299
1917	19.210±.458	17.540±.418	14.230±.360	14.650±.311
1918	15.440±.368	17.000±.405	12.425±.267	13.310±.282
1919	13.300±.317	15.000±.358	11.825±.256	13.405±.314
		Coefficients of Variability		
1912	17.63±.43		16.89±.37	
1913	31.05±.81		20.50±.46	
1914	20.68±.51		17.13±.36	
1915	23.93±.60	22.54±.56	21.32±.49	22.52±.51
1916	30.19±.78	24.54±.62	17.22±.39	17.35±.40
1917	31.03±.81	25.77±.65	18.28±.48	19.13±.42
1918	25.88±.66	26.67±.68	18.71±.42	20.20±.45
1919	32.40±.85	35.71±.95	20.53±.46	23.45±.58

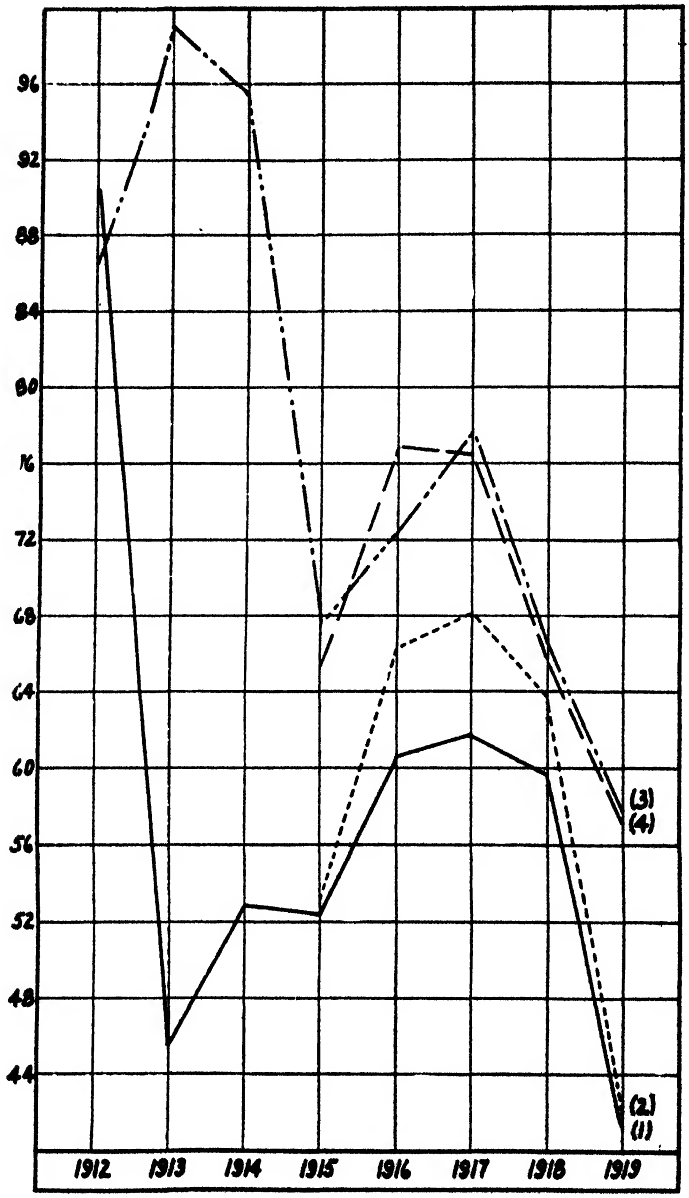

FIG. 4.—Average number of kernels per culm for the New York plants from home-grown and imported seed and the Montana plants from home-grown and imported seed. (1) New York home-grown; (2) New York imported; (3) Montana home-grown; (4) Montana imported.

With the exception of the first year, when the New York-grown plants averaged 4.190 ± .695 more kernels per culm, the average number of kernels per culm is larger for the Montana-grown plants. For the remainder of the test the Montana-grown plants averaged 23.176 ± .273 more kernels per culm than the New York-grown plants. This is a rather large difference, and indicates that environmental conditions in Montana are superior for oat production.

The average standard deviation for New York is 14.972 ± .128 and for Montana it is 14.570 ± .115.

There is greater variability for the New York-grown plants as shown by the coefficients of variability. This is especially true for the later years of the experiment.

The results of the tests grown at both stations from the imported seed are interesting, especially the means. These are shown graphically in Fig. 4.

The means for the New York-grown plants do not agree so closely as do those for the plants grown in Montana. They do, however, increase or decrease similarly, indicating that there is a tendency for them to vary uniformly. The means for the Montana-grown plants agree rather closely and indicate that the environment under which the plants grow has a greater effect than the seed used. At least this is so when dealing with a pure line.

This is borne out by the comparisons in the table. For the year 1919 the mean for the New York-grown plants from New York seed of 1918 is 41.050 ± .448, while in Montana plants grown from New York seed of the same crop have a mean of 57.160 ± .444, or an increase of 16.110 ± .631. For the same year the Montana crop grown in Montana from 1918 seed had a mean of 57.585 ± .363, while the same crop seed grown in New York gave a mean of only 42.000 ± .506, or an increase in Montana of 15.585 ± .623. These two differences are in very close agreement.

Other years show differences, although not in such close agreement. Thus, the differences for the same comparisons for 1917 are 14.697 ± .783 for the New York seed and 9.770 ± .780 for the Montana seed. All of this tends to support the statement made above that in a pure line test of oats, at least, the environment of the growing crop plays a more important part than do the conditions under which the seed was originally produced.

The standard deviations and coefficients of variability for the two lots of plants grown in each place generally agree, although there are some noticeable differences. Nevertheless, they tend to be high or low for the same environment regardless of the source of seed. The coefficients of variability for the plants grown in New York from Montana seed average higher than those for the Montana-grown plants.

TOTAL WEIGHT OF KERNELS

The total weight of kernels in grams was taken and the constants are given in Table 9.

There is a very wide difference in the weight of grain produced at the two stations, the yield for the Montana-grown plants being much greater than for the New York-grown plants. This is due to the more favorable conditions prevailing in Montana for oat production. The yield for certain years in New York is very low, and there is a marked decrease in the later years of the test. As stated above, this is due to the fact that the land used was less fertile and conditions for good yields were not so favorable.

The range for the New York-grown plants is from 1.945 ± .032 to 9.310 ± .110, or a difference of 7.365 ± .115. The range for the Montana-grown plants is much higher, being from 9.576 ± .118 to 28.048 ± .340, or a difference of 18.472 ± .360.

TABLE 9.—*Means, standard deviations, and coefficients of variability for total weight of kernels in grams.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
		Means		
1912	9.310±.110		19.688±.184	
1913	6.807±.099		28.048±.340	
1914	5.542±.065		19.434±.173	
1915	4.280±.065	4.337±.070	9.576±.118	9.758±.125
1916	3.537±.054	4.070±.057	16.590±.235	19.943±.267
1917	2 922±.054	3.357±.054	17.997±.233	16.080±.175
1918	3.225±.052	3.555±.059	14.138±.149	14.592±.155
1919	1.945±.032	2.110±.034	11.763±.152	11.110±.190
		Standard Deviations		
1912	3.266±.078		6.115±.130	
1913	2.939±.070		11.242±.240	
1914	1.942±.046		6.005±.122	
1915	1.923±.046	2.079±.050	3.760±.083	4.404±.089
1916	1.594±.038	1.701±.041	7.390±.163	8.480±.198
1917	1.587±.038	1.616±.039	6.520±.165	5.820±.124
1918	1.543±.037	1.750±.042	4.896±.105	5.184±.110
1919	0.963±.023	1.014±.024	4.965±.108	5.748±.135
		Coefficients of Variability		
1912	35.08± .93		31.06± .72	
1913	43.18±1.21		40.08± .98	
1914	35.04± .93		30.90± .69	
1915	44.93±1.27	47.94±1.38	39.26±1.00	45.13±1.17
1916	45.07±1.27	41.79±1.16	44.54±1.16	42.52±1.11
1917	54.31±1.63	48.14±1.39	36.23±1.03	36.19± .86
1918	47.84±1.38	49.23±1.43	34.63± .83	35.53± .84
1919	49.51±1.44	48.06±1.39	42.21±1.07	51.74±1.50

The standard deviations are, naturally, lower for the New York-grown plants. They follow the means rather closely in that as a rule the larger standard deviations are associated with the larger means, although there are some exceptions.

The coefficients of variability are larger for the New York-grown plants, indicating greater variability. In all cases the variability is high.

The results for the total weight of kernels for the plants grown in the two localities from imported seed are similar to those for the other characters. The mean weight for the New York-grown plants from the two sources of seed agrees very closely year by year. The same is true for the Montana-grown plants from the two seed sources. These comparisons are shown graphically in Fig. 5.

While in some cases the difference between the means for the two lots is significant, yet the difference is much less than that obtained when comparing the plants from the same seed under the two different environments. An example will make this clear. Take the results for the year 1916. The difference between the means for the plants grown in New York is 0.533 ±.079 gram, while the difference between the plants grown in New York and Montana from New York seed is 16.406 ± .272 grams. Again, for the same year, the difference between the Montana-grown plants from the two lots of seed is 3.353 ± .356 grams, while the difference between the two lots grown from Montana seed in Montana and New York is 12.520 ± .242 grams. From this it is apparent that the source of seed, so far as these data are concerned, is of less importance than growth conditions.

The standard deviations and coefficients of variability for the two groups of plants grown at the same place are in fairly close agreement.

AVERAGE WEIGHT OF KERNELS PER CULM

The average weight of kernels per culm, expressed in milligrams, was determined by dividing the total weight of kernels by the number of culms. The data are given in Table 10.

The data show that the average yield per culm is higher for the Montana-grown plants. This is very marked in certain years as, for example, 1913 and 1914, when the yield for the Montana-grown plants is over twice that of the New York-grown plants. In other years the difference is not so great, yet it is decidedly in favor of the Montana plants.

The variability, as measured by the coefficient of variability, is somewhat higher for the New York-grown plants.

The plants grown in each place from imported seed give results very similar to those obtained with the plants from home-grown seed.

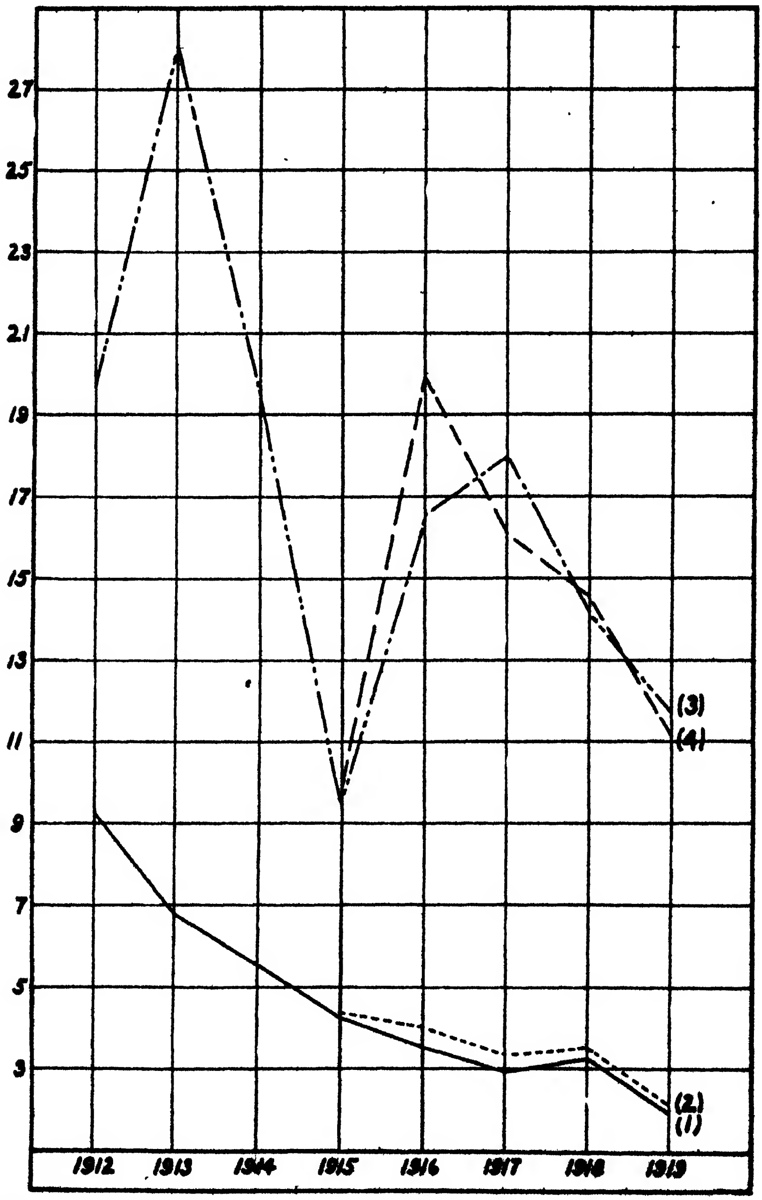

FIG. 5.—Total weight of kernels for the New York plants from home-grown and imported seed and the Montana plants from home-grown and imported seed. (1) New York home-grown; (2) New York imported; (3) Montana home-grown; (4) Montana imported.

The means are shown graphically in Fig. 6. The means of the plants grown in Montana from seed from both sources agree more closely than do those for the New York-grown plants.

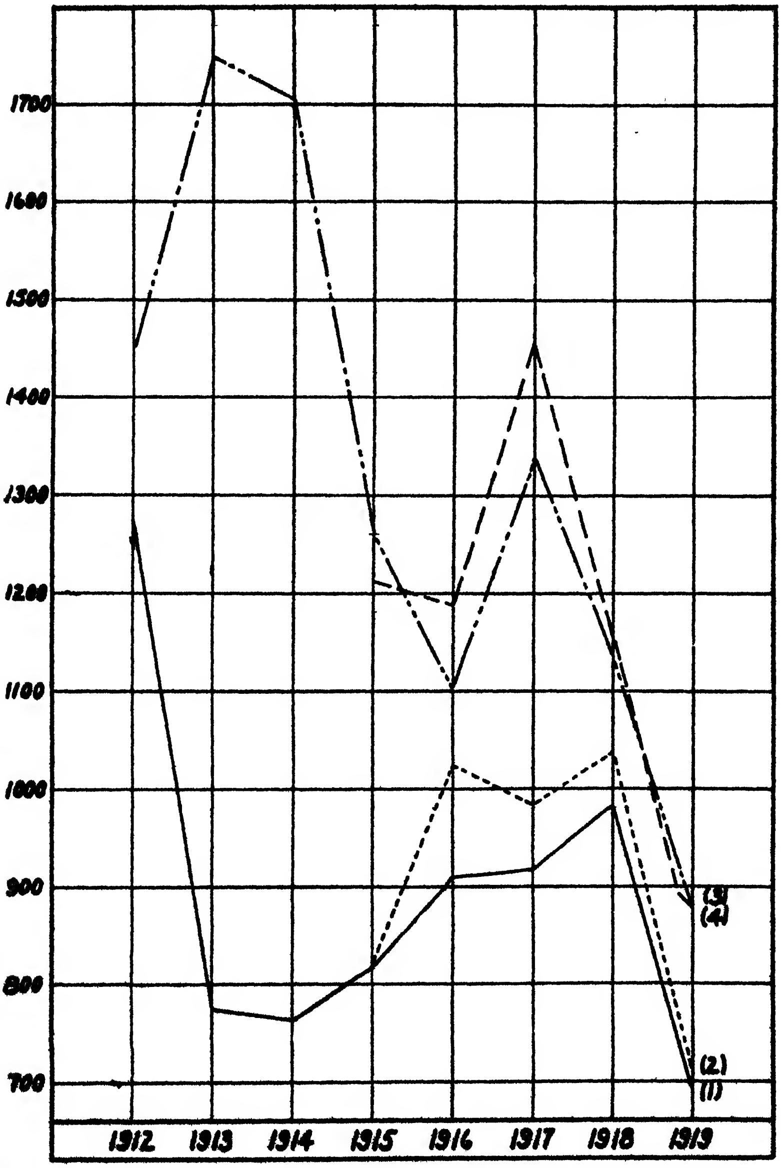

FIG. 6.—Average weight of kernels per culm for the New York plants from home-grown and imported seed and the Montana plants from home-grown and imported seed. (1) New York home-grown; (2) New York imported; (3) Montana home-grown; (4) Montana imported.

AVERAGE WEIGHT OF KERNEL

The average weight of kernel was determined by dividing the total weight of kernels by the total number of kernels, and is expressed in milligrams. These data are given in Table 11.

The average weight of kernel is somewhat higher for the Montana-grown plants. The average for the eight years is 15.658 ± .016 for the New York test and 17.099 ± .022 for the Montana test, giving a difference of 1.441 ± .027.

While the average for the Montana plants is higher, it is evident that the great difference in total yield as given in Table 9 is not

TABLE 10.—*Means, standard deviations, and coefficients of variability for ave age weight of kernels per culm in milligrams.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
		Means		
1912	1,266.750± 7.771		1,449.200± 7.620	
1913	775.250± 8.166		1,748.394±11.564	
1914	761.000± 5.780		1,705.640± 9.584	
1915	818.000± 7.103	821.750± 6.593	1,260.600± 8.950	1,213.750± 8.466
1916	911.000± 9.440	1,022.000± 9.087	1,104.900± 8.190	1,188.200± 8.440
1917	917.750±10.093	984.250± 8.896	1,338.450±11.263	1,438.220± 9.994
1918	983.500± 9.171	1,039.500±10.084	1,136.840± 7.809	1,153.360± 8.301
1919	694.750± 7.999	712.500± 8.287	882.670± 6.920	879.730± 8.055
		Standard Deviations		
1912	230.448±5.496		252.506±5.380	
1913	242.157±5.775		382.600±8.177	
1914	171.403±4.088		341.400±6.568	
1915	210.656±5.024	195.535±4.664	285.000±6.330	297.000±5.982
1916	279.962±6.677	269.474±6.427	262.500±5.290	268.000±5.970
1917	299.313±7.139	263.828±6.292	314.600±7.963	332.700±7.067
1918	271.989±6.487	299.065±7.133	257.300±5.522	276.900±5.870
1919	237.228±5.658	245.751±5.861	225.700±4.893	243.000±5.696
		Coefficients of Variability.		
1912	18.19±.45		17.42±.38	
1913	31.24±.81		21.88±.49	
1914	22.52±.56		20.02±.42	
1915	25.75±.65	23.79±.60	22.61±.53	24.47±.56
1916	30 73±.80	26.37±.67	23.76±.55	22.56±.53
1917	32.61±.86	26.80±.68	23.50±.63	23.13±.52
1918	27.66±.71	28.77±.74	22.63±.51	24.01±.54
1919	34.15±.90	34.49±.92	25.57±.59	27.62±.69

entirely due to the size of seed nor to the difference in number of kernels per culm (Table 8). It is rather due to the larger number of culms per plant. As shown earlier (Table 5), the average number of culms per plant is much higher for the Montana plants. This fact, together with the smaller differences in average weight of kernel

and in average number of kernels per culm, accounts for the great difference in total yield.

TABLE 11.—*Means, standard deviations, and coefficients of variability for average weight of kernel in milligrams.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
		Means		
1912	14.070±.036		16.730±.042	
1913	17.252±.045		17.612±.050	
1914	14.450±.040		17.794±.039	
1915	15.702±.051	15.645±.063	18.625±.034	18.498±.035
1916	15.120±.043	15.502±.040	15.622±.063	15.358±.052
1917	14.997±.042	14.645±.063	17.184±.113	17.803±.084
1918	16.515±.043	16.362±.044	17.087±.053	17.657±.048
1919	17.160±.063	17.300±.061	16.135±.058	15.871±.046
		Standard Deviations		
1912	1.082±.026		1.409±.030	
1913	1.345±.032		1.666±.036	
1914	1.172±.028		1.610±.027	
1915	1.526±.036	1.877±.045	1.093±.024	1.245±.025
1916	1.265±.030	1.190±.028	2.035±.045	1.663±.037
1917	1.244±.030	1.865±.044	3.169±.080	2.786±.059
1918	1.282±.031	1.295±.031	1.733±.037	1.588±.034
1919	1.883±.045	1.818±.043	1.888±.041	1.377±.032
		Coefficients of Variability		
1912	7.69±.18		8.42±.18	
1913	7.80±.19		9.46±.20	
1914	8.11±.19		9.05±.19	
1915	9.72±.23	12.00±.29	5.87±.13	6.73±.15
1916	8.37±.20	7.68±.18	13.03±.29	10.83±.24
1917	8.29±.20	12.73±.31	18.44±.48	15.65±.34
1918	7.76±.19	7.91±.19	10.14±.22	8.99±.19
1919	10.97±.26	10.51±.25	11.70±.26	8.68±.21

The standard deviations are smaller for the New York-grown plants, as are the coefficients of variability.

The means of the plants grown in each place from imported seed agree very closely with those of the plants from home-grown seed. These are shown graphically in Fig. 7.

The average of the means for the plants grown in New York from imported seed is 15.891 ± .025, while for the plants grown in Montana from imported seed it is 17.037 ± .025. The difference is 1.146 ± .035, agreeing very closely with the difference in means of the plants from home-grown seed.

The standard deviations for the two lots of plants grown at the same place agree fairly well, with an exception in New York in 1917. The coefficients of variability, however, do not agree so closely because of fluctuations in the means and standard deviations.

CORRELATION OF CHARACTERS

The various characters were correlated with each other to determine whether any significant differences occur under the different environments and whether the seed produced under different environments had any effect in changing the nature of the correlations.

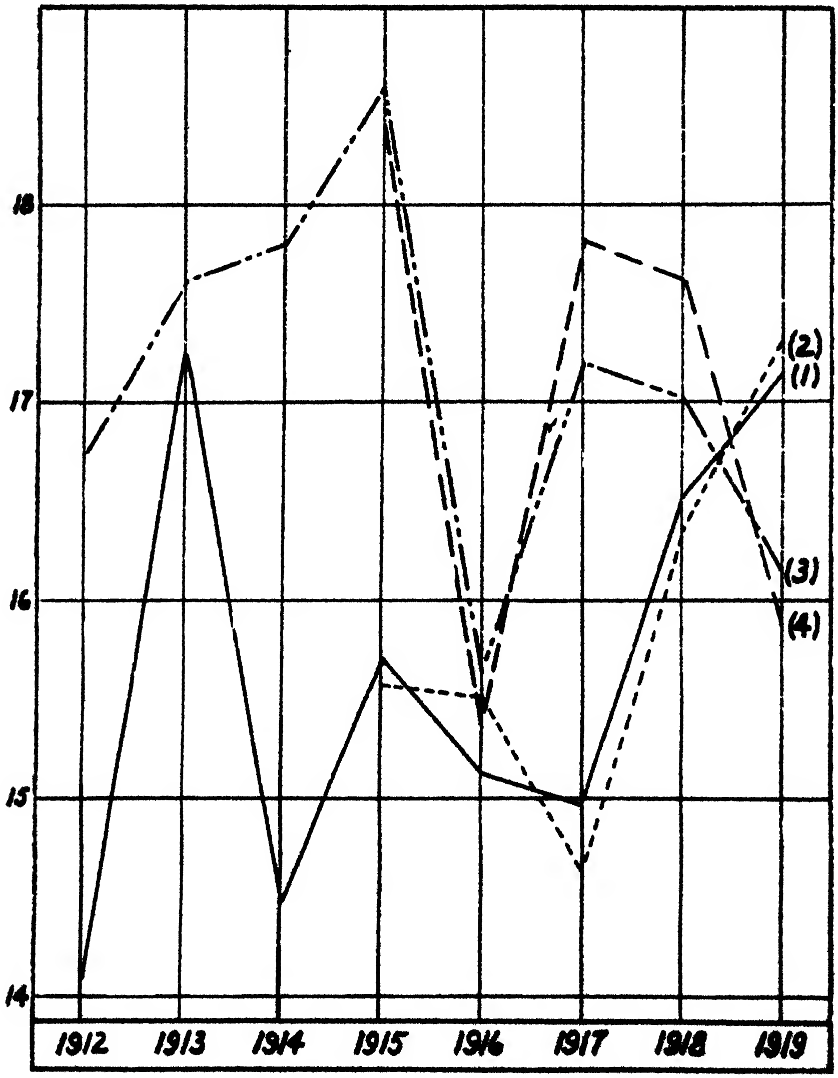

FIG. 7.—Average weight of kernel for the New York plants from home-grown and imported seed and the Montana plants from home-grown and imported seed. (1) New York home-grown; (2) New York imported; (3) Montana home-grown; (4) Montana imported.

NUMBER OF CULMS PER PLANT CORRELATED WITH OTHER CHARACTERS

The correlation coefficients for the correlations between number of culms per plant and other characters are given in Tables 12 and 13.

The correlation between number of culms per plant and average length of culm is found to be very variable, or unstable. For the plants grown in New York from New York seed the coefficient varies from 0.021 ± .034 to 0.456 ± .027. For the Montana-grown plants the correlation is somewhat higher on the average, although the correlation varies from 0.083 ± .029 to 0.496 ± .024.

The plants grown at each place from imported seed do not show any consistent behavior so far as the correlation coefficients are concerned. It does happen that for the plants grown in Montana the highest coefficient for each group is found in the same year, 1916. For the other years, however, there is no tendency for the values to vary consistently.

TABLE 12.—*Correlation coefficients between number of culms per plant and average length of culm, average length of head, and average number of kernels per culm.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
	Number of Culms per Plant, and Average Length of Culm, cm			
1912	0.400±.028		0.200±.029	
1913	0.456±.027		0.240±.028	
1914	0.138±.033		0.083±.029	
1915	0.021±.034	0.145±.033	0.352±.027	0.401±.024
1916	0.286±.031	0.134±.033	0.496±.024	0.638±.019
1917	0.221±.032	0.188±.033	0.246±.034	0.345±.026
1918	0.174±.033	0.375±.029	0.183±.029	0.312±.027
1919	0.152±.033	0.019±.034	0.394±.026	0.551±.023
	Number of Culms per Plant and Average Length of Head, cm			
1912	0.431±.027		0.391±.026	
1913	0.456±.027		0.350±.027	
1914	0.249±.032		0.086±.029	
1915	0.175±.033	0.246±.032	0.363±.027	0.269±.026
1916	0.409±.028	0.308±.031	0.477±.024	0.598±.020
1917	0.323±.030	0.299±.031	0.137±.035	0.231±.028
1918	0.262±.031	0.338±.030	0.201±.029	0.294±.027
1919	0.029±.034	−0.026±.034	0.321±.028	0.399±.028
	Number of Culms per Plant and Average Number of Kernels per Culm			
1912	0.302±.031		0.318±.027	
1913	0.237±.032		0.235±.029	
1914	0.069±.034		0.078±.029	
1915	0.058±.034	0.258±.031	0.249±.029	0.216±.015
1916	0.299±.031	0.200±.032	0.600±.020	0.642±.019
1917	0.227±.032	0.157±.033	0.271±.033	0.278±.028
1918	0.257±.031	0.309±.031	0.297±.028	0.321±.027
1919	−0.080±.034	−0.101±.033	0.398±.026	0.433±.027

The correlation between number of culms and average length of head for the different years gives results somewhat similar to those found with the number of culms and average length of culm. The highest value for both correlations for the New York-grown plants is found the same year, 1913. Similarly for the Montana-grown plants, in both correlations, the highest value occurs in 1916 and the lowest in 1914. This correlation also is found to be very variable.

TABLE 13.—*Correlation coefficients between number of culms per plant and average weight of kernels per culm, total weight of kernels, and average weight of kernel.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
Number of Culms per Plant and Average Weight of Kernels per Culm, mg				
1912	0.285±.031		0.237±.017	
1913	0.194±.032		0.238±.029	
1914	—0.094±.033		0.028±.029	
1915	—0.129±.033	0.021±.034	0.254±.029	0.183±.028
1916	0.297±.031	0.210±.032	0.528±.023	0.533±.023
1917	0.187±.033	0.080±.034	0.168±.035	0.146±.029
1918	0.169±.033	0.271±.031	0.304±.028	0.356±.026
1919	—0.080±.034	—0.122±.033	0.342±.027	0.399±.028
Number of Culms per Plant and Total Weight of Kernels, grams				
1912	0.874±.008		0.854±.008	
1913	0.755±.014		0.850±.008	
1914	0.783±.013		0.754±.012	
1915	0.824±.011	0.875±.008	0.802±.011	0 839±.008
1916	0.778±.013	0.789±.013	0.908±.006	0.924±.005
1917	0.787±.013	0.795±.012	0.803±.013	0.760±.013
1918	0.776±.013	0.818±.011	0.758±.013	0.781±.012
1919	0.627±.020	0.623±.021	0.843±.009	0.669±.018
Number of Culms per Plant and Average Weight of Kernel, mg				
1912	—0.059±.034		—0.073±.030	
1913	—0.167±.033		0.064±.030	
1914	—0.329±.030		0.078±.029	
1915	—0.453±.027	—0.237±.032	0.058±.031	0.048±.028
1916	0.054±.034	0.054±.034	0.192±.029	0.158±.031
1917	—0.111±.033	—0.164±.033	—0.065±.036	0.105±.030
1918	—0.141±.033	—0.031±.034	0.115±.030	0.182±.029
1919	0.005±.034	0.062±.034	0.029±.031	0.128±.033

The results for the plants grown from imported seed are similar to those for the plants from home-grown seed. One correlation, that for 1919 at New York, is negative. The values in New York are generally lower than those in Montana.

The number of culms per plant was correlated with the average number of kernels per culm. This correlation was found to be rather easily affected by environment. The correlation coefficients for New York plants range from — 0.080 ± .034 to 0.302 ± .031,

while those for Montana plants range from 0.078 ± .029 to 0.600 ± .020. It is evident that there is no yearly agreement between the two tests. Some of the correlations are very significant, while others are very low and not significant as compared with their probable errors.

The two lots of plants grown from imported seed give results quite similar to those obtained with plants from home-grown seed. At New York the range is from — 0.101 ± .033 to 0.309 ± .031, while at Montana the range is from 0.216 ± .015 to 0.642 ± .019. There is a higher correlation, generally, for the plants grown in Montana.

The correlation between the number of culms and the average weight of kernels per culm is shown in Table 13. The correlation between these two characters is very unstable as the correlation coefficients range from — 0.129 ± .033 to 0.533 ± .023. Even for the plants grown in New York from home-grown seed the correlation values vary from — 0.129 ± .033 to 0.297 ± .031. The Montana home-grown plants have an even greater range as the coefficient varies from 0.028 ± .029 to 0.528 ± .023.

The correlation coefficients for the plants grown in each locality from imported seed are also extremely variable. They are high or low, however, corresponding to the changes in the coefficients for the plants from home-grown seed. For example, for the New York material in 1915 the values are — 0.129 ± .033 and 0.021 ± .034 and for 1916 they are 0.297 ± .031 and 0.210 ± .032. Likewise, for the Montana material the correlation coefficients for 1915 are 0.254 ± .029 and 0.183 ± .028, while for 1916 they are much higher, 0.528 ± .023 and 0.533 ± .023. In 1917 the coefficients are both lower.

The number of culms per plant was correlated with the total weight of kernels. These data also are given in Table 13. The correlation coefficients for these characters show a very high, stable correlation for the different years. There is some variability, but the range is much less than in the correlations already discussed. For the plants grown in New York from home-grown seed, the range is from 0.627 ± .020 to 0.874 ± .008, while the range for the Montana plants from home-grown seed is from 0.754 ± .012 to 0.908 ± .006. We might expect this to be a high correlation, providing all or nearly all of the culms produced grain. From the results obtained it is evident that most of the culms produced some grain.

The correlation is also high for the plants grown from imported seed, and there is a rather close agreement in the different years for the plants from the two lots of seed. For example, in New York

for the year 1918, the correlation is high in both tests, being 0.776 ± .013 and 0.818 ± .011, while in 1919 it is much lower, 0.627 ± .020 and 0.623 ± .021. Similar results are found with the Montana material with an important exception in 1919. In this year the correlation is high for the Montana seed and low for the New York seed.

The correlation between number of culms per plant and the average weight of kernel is also shown in Table 13.

These results are similar to those published by Love and Leighty (2), Leighty (3), and others, showing this correlation to be very unstable. The correlations are both plus and minus, and in many cases there is no significant relation. The values for the New York plants from home-grown seed vary from — 0.453 ± .027 to 0.054 ± .034. For the Montana plants from home-grown seed the range is

TABLE 14.—*Correlation coefficients between average length of culm and average length of head, average number of kernels per culm, and average weight of kernels per culm.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
	Average Length of Culm, cm, and Average Length of Head, cm			
1912	0.765±.014		0.701±.015	
1913	0.863±.009		0.772±.012	
1914	0.695±.017		0.770±.012	
1915	0.784±.013	0.701±.017	0.800±.011	0.811±.098
1916	0.807±.012	0.717±.016	0.694±.018	0.952±.003
1917	0.785±.013	0.774±.014	0.746±.016	0.419±.025
1918	0.762±.014	0.779±.013	0.709±.015	0.689±.016
1919	0.734±.016	0.759±.014	0.776±.012	0.808±.012
	Average Length of Culm, cm, and Average Number of Kernels per Culm			
1912	0.667±.019		0.549±.021	
1913	0.739±.015		0.561±.021	
1914	0.714±.017		0.756±.012	
1915	0.738±.015	0.726±.016	0.766±.013	0.764±.012
1916	0.794±.012	0.775±.013	0.732±.015	0.800±.011
1917	0.824±.011	0.761±.014	0.448±.029	0.752±.013
1918	0.804±.012	0.767±.014	0.618±.019	0.851±.008
1919	0 638±.020	0.684±.018	0.579±.020	0.770±.013
	Average Length of Culm, cm, and Average Weight of Kernels per Culm, mg			
1912	0.669±.019		0.576±.020	
1913	0.745±.015		0.572±.020	
1914	0.688±.018		0.749±.013	
1915	0.758±.014	0.768±.014	0.808±.011	0.783±.011
1916	0.837±.010	0.811±.012	0.680±.017	0.798±.011
1917	0.836±.010	0.774±.014	0.669±.020	0.633±.018
1918	0.785±.013	0.775±.013	0.834±.009	0.837±.009
1919	0.683±.018	0.692±.018	0.781±.012	0.708±.017

not so great, varying from — 0.073 ± .030 to 0.192 ± .029. In only one instance, in 1916, may the correlation be considered as significant for the Montana series. There are more cases of significant correlation found in the New York plants.

The plants grown from imported seed show results somewhat similar to those obtained in the home-grown plants. For the plants from imported seed grown in New York, the highest correlation is found in 1915, as in the plants from home-grown seed. For the plants from imported seed grown in Montana the correlations are all positive, although only two, in 1916 and 1918, may be considered significant.

AVERAGE LENGTH OF CULM CORRELATED WITH OTHER CHARACTERS

The average length of culm was correlated with the other characters and these data are shown in Tables 14 and 15. The correlation between average length of culm and number of culms has already been discussed.

The average length of culm correlated with the average length of head shows a very high, positive relation. This is to be expected, since the factors that influence the length of culm should affect the length of head in a very similar manner. For the most part, the results would tend to class this as a stable correlation. For the New

TABLE 15.—*Correlation coefficients between average length of culm and total weight of kernels and average weight of kernel.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
	Average Length of Culm, cm, and Total Weight of Kernels, grams			
1912	0.574±.023		0 440±.024	
1913	0.738±.015		0.434±.025	
1914	0.511±.025		0.428±.023	
1915	0.417±.028	0.460±.027	0.693±.016	0.707±.014
1916	0.639±.020	0.522±.025	0.632±.019	0.677±.020
1917	0.621±.021	0.571±.023	0.559±.025	0.607±.019
1918	0.574±.023	0.628±.020	0.748±.013	0.709±.015
1919	0.567±.023	0.524±.024	0.647±.018	0.697±.017
	Average Length of Culm, cm, and Average Weight of Kernel, mg			
1912	0.038±.034		0.161±.029	
1913	0.012±.034		0.127±.030	
1914	0.270±.031		0.335±.026	
1915	0.201±.032	0.089±.033	0.423±.026	0.370±.025
1916	0.219±.032	0.308±.031	0 345±.028	0.386±.027
1917	0.070±.034	0.050±.034	0.194±.035	0.111±.030
1918	0.083±.033	0.280±.031	0.159±.030	0.443±.024
1919	0.155±.033	—0.064±.034	0.516±.022	0.264±.031

York plants from home-grown seed the range is from 0.695 ± .017 to 0.863 ± .009, and for the Montana plants from home-grown seed it is from 0.694 ± .018 to 0.800 ± .011.

The plants grown in New York from imported seed give practically the same correlation coefficient from year to year. On the other hand, the correlations obtained with the plants grown in Montana from imported seed are extremely variable, ranging from 0.419 ± .025 to 0.952 ± .003.

The average length of culm was correlated with the average number of kernels per culm, giving a very high correlation. In general the correlation is higher for the New York plants than for the Montana plants, five of the coefficients for the Montana plants being lower than the lowest coefficient for the New York plants.

The plants grown from imported seed gave correlation values very similar to those for the plants from home-grown seed. For some unexplained reason the plants grown in Montana from imported seed gave higher correlation coefficients than the plants grown in Montana from home-grown seed.

The average length of culm was correlated with the average weight of kernels per culm and the data are given in Table 14. The correlation coefficients are high and it is evident that this is a rather stable relationship. The range for the two localities is not great, being from 0.669 ± .019 to 0.837 ± .010 for the New York plants, and from 0.572 ± .020 to 0.834 ± .009 for the Montana material.

The plants grown from imported seed give results similar to those for the plants from home-grown seed.

The average length of culm correlated with total weight of kernels also shows high, positive, and stable correlations (Table 15). The lowest correlation for the New York material is in 1915 with a correlation coefficient of 0.417 ± .028. The highest is for 1913 with a value of 0.738 ± .015. The range is practically the same for the Montana p ants from home-grown seed. The lowest correlation is 0.428 ± .023 in 1914 and the highest value is 0.748 ± .013 in 1918.

The correlation coefficients obtained for the plants grown from imported seed are similar to those for the plants from home-grown seed. There is no indication that the source of seed has any influence.

The correlation between average length of culm and average weight of kernel was found to be an unstable one (Table 15). For all the material it varies from — 0.064 ± .034 to 0.516 ± .022. In general, the correlation is lower for the New York plants than for the Montana plants. For the New York data there are really only 5 cases

out of 13 where the correlation may be said to be significant. For the Montana plants there are at least 10 out of 13. It is apparent that the tendency is for the taller plants in Montana to produce kernels of somewhat larger size.

AVERAGE LENGTH OF HEAD CORRELATED WITH OTHER CHARACTERS

The correlation between the average length of head and number of culms and with average length of culm has already been discussed. The relation between the average length of head and other characters is shown in Table 16.

As might be expected, these correlations agree rather closely with those found between the average length of culm and the different characters. As noted when discussing the correlation between the average length of culm and average length of head, the factors which influence one of these characters must have a similar effect, at least to a considerable degree, on the other character.

The correlation between the average length of head and average number of kernels per culm is very close and rather constant. If anything, it is somewhat more uniform and stable than that between the average length of culm and average number of kernels per culm. The range in value of the correlation coefficients is not very great, as for all the values given, both for Montana and New York, it ranges from 0.737 ± .015 to 0.875 ± .009.

The relation between the average length of head and the average weight of kernels per culm is also found to be very close. While the range between the lowest and highest coefficients is somewhat greater than in the characters just discussed, being from 0.605 ± .018 to 0.851 ± .008, in all cases there is a high positive relationship.

A close correlation also exists between the average length of head and total weight of kernels. This is to be expected, since there is also a close correlation between total weight of kernels and average length of culm. The correlation is not as high as those just discussed, but all the coefficients are very significant. The range is from 0.488 ± .027 to 0.748 ± .015.

The correlation between the average length of head and average weight of kernel is extremely variable from year to year and in the different localities. This coincides with the relationship between the average length of culm and average weight of kernel. The coefficients for the New York plants are also lower than those for the Montana plants. In New York 5 out of 13 are negative, although none of them is significant. In fact, only 2 of the 13 coefficients are of possible significance. For the Montana plants only in 1 case out

of 13 is there a negative correlation. Nine of the 13 are significant, although only 1 (with the plants from home-grown seed in 1919) is very high.

TABLE 16.—*Correlation coefficients between average length of head and average number of kernels per culm, average weight of kernels per culm, total weight of kernels, and average weight of kernel.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
	Average Length of Head, cm, and Average Number of Kernels per Culm			
1912	0.751±.015		0.797±.011	
1913	0.769±.014		0.777±.012	
1914	0.744±.015		0.793±.011	
1915	0.838±.010	0.783±.013	0.805±.011	0.875±.009
1916	0.797±.012	0.770±.014	0.766±.013	0.839±.010
1917	0.825±.011	0.787±.013	0.763±.015	0.854±.008
1918	0.833±.010	0.779±.013	0.828±.010	0.819±.010
1919	0.737±.015	0.748±.015	0.843±.009	0.869±.008
	Average Length of Head, cm, and Average Weight of Kernels per Culm, mg			
1912	0.685±.018		0.740±.014	
1913	0.767±.014		0.746±.013	
1914	0.682±.018		0.605±.018	
1915	0.777±.013	0.709±.017	0.830±.010	0.843±.008
1916	0.818±.011	0.750±.015	0.643±.019	0.694±.016
1917	0.809±.012	0.729±.016	0.682±.019	0.692±.016
1918	0.794±.012	0.762±.014	0.724±.014	0.706±.015
1919	0.756±.014	0.739±.015	0.851±.008	0.814±.011
	Average Length of Head, cm, and Total Weight of Kernels, grams			
1912	0.616±.021		0.644±.018	
1913	0.748±.015		0.619±.019	
1914	0.611±.021		0.532±.021	
1915	0.551±.023	0.522±.025	0.701±.016	0.645±.017
1916	0.695±.017	0.637±.020	0.599±.021	0.697±.016
1917	0.679±.018	0.633±.020	0.488±.027	0.575±.020
1918	0.637±.020	0.625±.021	0.545±.021	0.589±.020
1919	0.541±.024	0.506±.025	0.697±.016	0.726±.016
	Average Length of Head, cm, and Average Weight of Kernel, mg			
1912	—0.125±.033		—0.006±.030	
1913	—0.085±.033		0.063±.030	
1914	0.015±.034		0.155±.022	
1915	0.007±.034	—0.113±.033	0.336±.028	0.247±.011
1916	0.175±.033	0.102±.033	0.244±.030	0.180±.021
1917	—0.054±.034	0.022±.034	0.118±.035	0.059±.030
1918	0.043±.034	0.178±.033	0.164±.030	0.176±.029
1919	0.036±.034	—0.146±.033	0.448±.025	0.309±.030

This relationship is usually found to be extremely variable. There is apparently no difference in the plants grown from home-grown and imported seed so far as the correlation is concerned.

AVERAGE NUMBER OF KERNELS PER CULM CORRELATED WITH OTHER CHARACTERS

The correlation between the average number of kernels per culm and certain other characters has already been discussed. The correlation with average weight of kernels per culm, total weight of kernels, and average weight of kernel is shown in Table 17.

The correlation between the average number of kernels per culm and average weight of kernels per culm is very high and very consistent, as would be expected. The range is not very great, especially

TABLE 17.—*Correlation coefficients between average number of kernels per culm and average weight of kernels per culm, total weight of kernels, and average weight of kernel.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
Average Number of Kernels per Culm and Average Weight of Kernels per Culm, mg				
1912	0.899±.006		0.871±.007	
1913	0.947±.003		0.870±.007	
1914	0.894±.007		0.860±.007	
1915	0.885±.007	0.861±.009	0.953±.003	0.981±.001
1916	0.951±.003	0.932±.004	0.898±.006	0.889±.007
1917	0.947±.003	0.886±.007	0.822±.012	0.808±.010
1918	0.938±.004	0.947±.003	0.896±.006	0.918±.005
1919	0.924±.005	0.936±.004	0.980±.001	0.947±.003
Average Number of Kernels per Culm and Total Weight of Kernels, grams				
1912	0.642±.020		0.659±.017	
1913	0.739±.015		0.615±.019	
1914	0.565±.023		0.633±.017	
1915	0.520±.025	0.529±.024	0.702±.016	0.661±.016
1916	0.731±.016	0.671±.019	0.806±.011	0.830±.010
1917	0.706±.017	0.611±.021	0.676±.019	0.697±.015
1918	0.710±.017	0.726±.016	0.704±.015	0.761±.013
1919	0.565±.023	0.581±.022	0.756±.013	0.834±.010
Average Number of Kernels per Culm and Average Weight of Kernel, mg				
1912	—0.119±.033		—0.101±.030	
1913	—0.138±.033		0.026±.030	
1914	0.130±.033		0.149±.028	
1915	0.039±.034	—0.155±.033	0.162±.023	0.243±.027
1916	0.027±.034	0.109±.033	0.317±.028	0.363±.027
1917	—0.047±.034	—0.131±.033	0.043±.036	0.050±.030
1918	0.075±.034	0.176±.033	0.224±.029	0.358±.026
1919	—0.132±.033	—0.281±.031	0.447±.025	0.368±.029

for the New York plants from home-grown seed, being from 0.885 ± .007 to 0.951 ± .003. It is somewhat greater for the Montana plants from home-grown seed, as the range is from 0.822 ± .012 to 0.980 ± .001.

The plants grown from imported seed give practically the same results. All correlation coefficients are high and apparently no effect of the source of seed is evident.

The correlation between the average number of kernels per culm and total weight of kernels shows a high positive correlation. It is not so high as that just discussed but is significant in all cases. The correlation is somewhat higher for the Montana-grown plants. The range for the plants grown in New York from home-grown seed is from 0.520 ± .025 to 0.739 ± .015, while for the plants from home-grown seed in Montana it is from 0.615 ± .019 to 0.806 ± .011.

The plants grown from imported seed show about the same relationship as do those from home-grown seed. The correlation coefficients tend to vary for the different years in the same direction as do those for plants from home-grown seed. Thus, in New York the coefficients for the two lots of plants in 1915 are 0.520 ± .025 and 0.529 ± .024, while in 1916 they are 0.731 ± .016 and 0.671 ± .019. Similar comparisons are found for the Montana material.

The correlation between the average number of kernels per culm and the average weight of kernel is found to be very unstable (Table 17). This relationship is quite similar to those found when the average weight of kernel is correlated with other characters. The range for all the coefficients determined is from — 0.281 ± .031 to 0.447 ± .025. For the New York plants 7 out of 13 values are negative, although only one or two may be considered significant. These are — 0.155 ± .033 and — 0.281 ± .031 for the plants grown from imported seed. The first of these is so low as to be on the border line. Only one of the positive correlations for the New York plants is of significance. That is for the plants grown from imported seed in 1918, with a coefficient of 0.176 ± .033.

The correlation coefficients for the Montana plants are higher in value. Only 1 out of 13 is negative, while of the 12 positive correlations 9 may be considered significant. There is, then, a slight tendency in Montana for the plants that produce the larger number of kernels also to produce somewhat larger kernels.

When comparing the results obtained from the imported seed, it is very evident that the source of seed is not the important consideration, but rather the environment under which the plants develop. This is clearly brought out by comparing the results from plants

grown in both places from seed produced in Montana. For example, in 1919, the correlation coefficient in Montana is 0.447 ± .025, while for the plants grown in New York from Montana seed it is — 0.281 ± .031. The plants grown in Montana in 1919 from New York seed give a correlation coefficient of 0.368 ± .029, a value which agrees very well with 0.447 ± .025.

CORRELATION BETWEEN AVERAGE WEIGHT OF KERNELS PER CULM AND TOTAL WEIGHT OF KERNELS AND AVERAGE WEIGHT OF KERNEL

Other correlations with the average weight of kernels have already been discussed. The data for the correlations between average weight of kernels per culm and total weight of kernels and average weight of kernel are given in Table 18.

The average weight of kernels per culm shows a high, positive correlation with the total weight of kernels on the plant. With the exception of the results in New York for 1914 and 1915 from home-grown seed and for 1915 from imported seed, the coefficients are all high. Even these three are high enough to show an undoubted positive relationship.

Again the results from imported seed are similar to those from home-grown seed.

TABLE 18.—*Correlation coefficients between average weight of kernels per culm and total weight of kernels and average weight of kernel.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
Average Weight of Kernels per Culm, mg, and Total Weight of Kernels, grams				
1912	0.678±.018		0.663±.017	
1913	0.746±.015		0.643±.018	
1914	0.488±.026		0.671±.016	
1915	0.392±.029	0.453±.027	0.709±.016	0.623±.017
1916	0.752±.015	0.703±.017	0.740±.014	0.799±.011
1917	0.700±.017	0.613±.021	0.694±.019	0.699±.015
1918	0.686±.018	0.728±.016	0.728±.014	0.825±.010
1919	0.620±.021	0.601±.022	0.776±.012	0.825±.011
Average Weight of Kernels per Culm, mg, and Average Weight of Kernel, mg				
1912	0.256±.032		0.349±.026	
1913	0.075±.034		0.372±.026	
1914	0.447±.027		0.567±.020	
1915	0.405±.028	0.230±.032	0.426±.026	0.429±.023
1916	0.236±.032	0.393±.029	0.738±.014	0.681±.017
1917	0.178±.033	0.265±.031	0.561±.025	0.663±.017
1918	0.335±.030	0.382±.029	0.601±.019	0.610±.019
1919	0.133±.033	—0.041±.034	0.712±.015	0.552±.023

The relation between the average weight of kernels per culm and the average weight of kernel is a very good example of an unstable correlation and shows the influence of environment. Some very low coefficients result, as — 0.041 ± .034 for the plants grown in New York from imported seed in 1919, and again rather high ones, as 0.738 ± .014, for the plants grown in Montana from home-grown seed in 1916.

The range for all the New York results is from — 0.041 ± .034 to 0.447 ± .027, and for all the Montana results it is from 0.349 ± .026 to 0.738 ± .014. Three out of 13 cases for the New York plants show no significant relation, while in Montana all of the coefficients are significant and positive.

The plants grown from imported seed give results very similar to those from home-grown seed.

CORRELATION BETWEEN TOTAL WEIGHT OF KERNELS AND AVERAGE WEIGHT OF KERNEL

The data for this correlation are given in Table 19.

We are again dealing with an unstable correlation. For the New York plants there is little indication of any relation existing between these characters. Considering all the results, the range is from — 0.194 ± .032 to 0.216 ± .032. These two values and the one for 1918 from imported seed, 0.212 ± .032, are the only ones that may be considered to be of any significance.

On the other hand, all of the coefficients obtained from the plants grown in Montana are positive, and all, with one exception in 1912, are significant.

It is very clear that environment has much to do with determining this relationship and that from year to year in the same location, due to different weather factors, there will be considerable change in the value of the correlation coefficient.

TABLE 19.—*Correlation coefficients between total weight of kernels in grams and average weight of kernel in milligrams.*

Year	New York seed grown in New York	Montana seed grown in New York	Montana seed grown in Montana	New York seed grown in Montana
1912	0.096±.033		0.139±.030	
1913	—0.041±.034		0.215±.029	
1914	0.032±.034		0.263±.027	
1915	—0.194±.032	—0.104±.033	0.275±.029	0.197±.027
1916	0.158±.033	0.216±.032	0.441±.025	0.391±.026
1917	0.019±.034	0.012±.034	0.257±.033	0.262±.028
1918	0.067±.034	0.212±.032	0.355±.027	0.472±.023
1919	0.104±.033	0.016±.034	0.437±.025	0.736±.015

In considering all of the correlations made we have dealt with the correlation coefficient only. In doing so we have not been unmindful of the fact that in some cases the correlation was not strictly linear; and that the correlation ratio would express the relationship better. However, a careful examination of all the tables indicated that for the most part the difference between the correlation ratio and correlation coefficient would be rather slight, and so far as the main study is concerned, would not change the conclusions.

The effect of the correlation ratio would be to show a closer relationship, and since the point at issue is rather to determine whether growing the seed for a considerable period of time under different environments produces any lasting change, there are no cases where the conclusions would be altered by having calculated the correlation ratio.

DISCUSSION OF RESULTS

The analysis of the soils on which the oats used in these tests were grown in New York and Montana shows that the New York soil contains 50% more organic matter and slightly more phosphorus than the Montana soil, while the Montana soil contains over four times as much calcium and upwards of twice as much potassium as the New York soil. The Montana soil is more favorable for the growth of grain crops than the New York soil.

Considering the climatic factors, it is shown that New York has more degrees of growing temperature during the growing season than Montana; while Montana has more daylight hours, a higher percentage of daylight hours having sunshine, and when the percentage of daylight hours is multiplied by the number of degrees of growing temperature it is found that the davlight-sunshine-growing-temperature factor is higher in Montana than in New York. The climatic conditions favor heavier growth in Montana than in New York.

Data obtained with the same pure line of oats grown for a period of eight years in Montana and in New York are presented. These data have been analyzed biometrically to determine what changes, if any, are effected by growing the plants under widely different environments.

The plants grown in Montana were generally larger and produced more culms and more grain. While plants of large size were obtained, the analysis of the results indicates that the nature of the variability of the plants produced under the different environments was practically the same.

There were some instances in which the variability was greater in New York than in Montana, as, for example, in the average number

of kernels per culm and the average weight of kernels per culm. Again, higher variability for the average weight of kernel was obtained with the Montana-grown plants. Various factors, such as the different environmental conditions under which the plants were grown, brought about these changes in variability. These conditions affected the means or standard deviations, causing higher or lower coefficients of variability.

Although the plants grown in Montana were larger, produced more grain, and had a larger average weight of kernel, it is evident that this increase is not permanent. The data obtained from the lots of imported seed show that there is really no carry-over effect, but that the environment under which the plants develop is the most important factor. Even the slightly larger seed produced in Montana does not seem to have any effect on the plants grown from this seed in New York.

While it may be unwise to generalize from these data, it is clear that, so far as this pure line of oats is concerned, the environment under which the seed develops does not have any measurable effect when the seed is grown in a new locality. This fact has a bearing on agricultural practice. It is entirely possible that when dealing with a badly mixed commercial variety this would not be true. It is a rather general idea that it is necessary to bring in seed, especially of oats, from a locality where better crops are produced. It is very doubtful, however, that importation, as a general thing, is as beneficial as it is believed to be.

The correlation of characters is affected by the different environments, more noticeably with certain characters than with others. While this has been noted in discussing characters, it may be well to recall some of the more important. The correlation between the total weight of kernels and average weight of kernel is higher in Montana than in New York. The same is true of the correlation between the average length of culm and the average weight of kernel.

Certain correlations were found to be high and stable, while others are very unstable. The latter are easily affected by environment, either in the same locality in different years or in widely different localities.

The general tendency for the correlations obtained with the plants grown from imported seed is to agree rather closely with those obtained with the plants from home-grown seed.

The general conclusion is that, so far as these data are concerned, environment is more important than source of seed.

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GOAT GRASS OR WILD WHEAT (*AEGILOPS TRIUNCIALIS*)[1]

P. B. KENNEDY[2]

The presence of a mechanically injurious weed in the fields and on the ranges in certain parts of California is of sufficient importance to botanists, agronomists, and stock men to warrant a discussion of its habits, occurrence, distribution and general characteristics

It belongs to the genus *Aegilops* which is a segregate from the cultivated wheats, *Triticum*.

As the species of *Aegilops* are found in the same general region in Europe as the wheats, it is somewhat surprising that they have not long since infested the wheat fields of the United States more generally.

Boissier (1)[3] describes 11 species of *Aegilops* as occurring in the Mediterranean region and northern Africa. Rouy (2) recognizes three species in France. In the United States two species occur as alien immigrants.

A review of the literature and the examination of herbarium material of *Aegilops* show that the species are very polymorphous. Rouy (2) describes two subspecies and seven varieties of *Aegilops ovata*. Popova (3) describes nine varieties of *Ae. triuncialis*, six of *Ae. cylindrica*, and three of *Ae. crassa*. According to this author, *Ae. triuncialis* is not affected by rust and has a solid straw, while *Ae. cylindrica*, *squarrosa*, and *crassa* have a hollow straw. The nonsusceptibility of *Ae. triuncialis* to rust infestation corresponds to the durum group of wheats, while the susceptibility of the *Ae. cylindrica* group corresponds to the soft wheats.

The susceptibility or nonsusceptibility of the different species of *Aegilops* to parasitic fungi may be of great importance to those engaged in cereal breeding. The presence of solid or hollow straw as differentiating characters does not appear to be well founded as plants of *Ae. triuncialis* grown in Berkeley produced a well-marked hollow straw. Herbarium specimens from Europe showed a variation from a solid straw to a hollow straw. This character of the straw seems to be inconstant and is due perhaps to environment and age.

The fact that *Ae. triuncialis* is very much at home in hard soil on dry slopes makes it a very undesirable weed as it is apt to spread over large areas very rapidly.

[1]Contribution from the Department of Agronomy, College of Agriculture and Agricultural Experiment Station, University of California, Berkeley, Calif. Received for publication October 2, 1928.

[2]Professor of Agronomy and Agrostologist in the Station.

[3]Reference by number is to "Literature Cited," p. 1296.

Field acquaintance with *Aegilops* began in July, 1917, when a letter was received from G. P. Weldon, then Chief Deputy, Commission of Horticulture, Sacramento, California, which stated the following:

"I am sending you today by parcel post sample of a grass which was collected on the line between Eldorado and Sacramento counties near Clarkville. This grass is said to be very injurious. It was noticed for the first time about 3 years ago where some cattle from Mexico had been pastured. This season it is said to have practically destroyed a crop of wheat. Will you kindly let me know the name, if possible?"

The specimen was identified as *Triticum triuncialis*, and it was recommended that every effort be made to eradicate it.

In 1919, L. Y. Leonard, who was collecting grasses in their relation to cereal diseases for the United States Department of Agriculture, brought a very mature specimen and a few seeds from Washington State College, Pullman, Washington, accompanied by the following note: "Collected around football field; growing in small clumps; plentiful; July 12, 1919."

Plants were grown from this seed in the Grass Garden at Berkeley under X 3112 and identified as *Ae. cylindrica*. This species is found as a weed in several other states but not in California.

The next occurrence was in 1921 when H. P. Stabler, then Horticultural Commissioner of Yuba County, brought in a specimen, stating that it was found wild in wheat. It proved to be *Aegilops triuncialis*. There is no record of the exact locality where the specimen was collected. It grew quite readily in the Grass Garden at Berkeley.

So far as is known, *Aegilops triuncialis* is the only species of *Aegilops* found as a weed in California, although there is every reason to believe that there may be others that have not yet become sufficiently abundant to attract attention. With fair accuracy then, it can safely be stated that goat grass has occurred as a weed in California since about 1915, and it may have been here very much earlier but remained undiscovered. After a lapse of six years, during which time no doubt the grass was multiplying rapidly, attention was again called to *Aegilops* by Ethelbert Johnson then botanist of the State Department of Agriculture. In the summer of 1927 the grass was identified as *Aegilops triuncialis*. Mr. Johnson stated that he had received it from H. L. Leonard, Horticultural Commissioner for Calaveras County, California, who reported that the very pointed fruit entered the eyes of hogs, penetrating to the brain and causing death.

Since 1927, W. C. Jacobsen of the Bureau of Plant Quarantine and Pest Control for the State of California; W. P. Wing, Secretary of the California Wool Growers Association; M. W. Talbot, in charge of Weed Investigations for the United States Department of Agriculture; the College of Forestry of the University of California; the Bureau of Forestry of the United States Department of Agriculture; and C. E. Leighty, Agronomist in charge, Eastern Wheat Investigations, have all been more or less interested in *Aegilops* as a weed. Previous to this outbreak of *Ae. triuncialis* in California Leighty has been interested in *Ae. cylindrica* and *Ae. triuncialis* in their relation to wheat. European investigators report natural and artificial hybridization with wheat, and Leighty, *et al* (4) report having made such crosses at Arlington in 1923.

The extent of the infestation of *Ae. triuncialis* is no doubt much larger than at first supposed as new areas are periodically being reported and the old areas are increasing in size. According to Mr. Leonard of Calaveras County, it occurs first as scattered plants rapidly making solid patches, there being about 60 acres of thoroughly established general heavy infestation and an additional 200 acres of scattered infestation. It is troublesome on the grazing lands and slowly spreading to cultivated areas. There is a large valley adjacent to the grazing area which is infested. This will be serious unless controlled and eradicated. It occurs naturally on fairly level rolling lands with rock croppings and shallow soils of an arid type. Some of this land is plowable. Stock eat sparingly of the young grass and avoid entirely grazing the mature plants. The ripe heads become entangled in the wool of sheep.

The problem of control and eradication has been taken up by the Bureau of Plant Quarantine and Pest Control of the State Department of Agriculture under the direction of W. C. Jacobsen.

As goat grass is an annual the first essential is the prevention of the production of seed on areas now infested. Stock, especially sheep, should not be permitted to graze on or traverse areas at the time the heads are mature as this is the most prolific source for the dispersal of the seed.

Burning over the ground when the plants are dry is only a partial remedy as it has a tendency to singe the beards without destroying the seed.

The most certain method of eradication would be the sterilization of the soil so that the seeds which are in the soil would not germinate. This can be done by the use of heavy applications of salt, oils, arsenicals, or sodium chlorate and, although the initial expenditure is heavy,

FIG. 1.—*Aegilops triuncialis.*

A, entire plant (X 0.3); B, spike (X 1); C, a single spikelet (X 1); D, the 3-awned glume (X 1); E, dorsal and ventral view of a caryopsis (X 2.3).

in the long run in would be found to be the cheapest and most certain. When wild wheat occurs on grain land a careful system of clean fallow and cutting the cereal crop for hay when quite young should soon eradicate it.

The figures and description of *Ae. cylindrica* by Percival (5) are sufficient to identify this species, but no adequate description of *Ae. triuncialis* seems to be available in English.

We append the following key of the two species now occurring as weeds in the United States with a description and illustration (Fig. 1) of *Ae. triuncialis*.

Glumes of the lower spikelets awnless or with very short awns. *Ae. cylindrica.*
Glumes of the lower spiklets with three long awns. *Ae. triuncialis.*

Aegilops triuncialis.

Plant from 8 to 20 inches tall with few to many culms: sheaths and blades with scattered white horizontal hairs when young, and more or less glabrous towards maturity: culms smooth, solid when young but hollow with age: spike about 3 inches long including the awns, elongate, subcylindrical, attenuate, consisting of 4 to 7 spikelets, the lower broad and fertile, the upper rudimentary: lower spikelets 2–3 flowered, about 10 mm long (minus the awns), equalling or slightly shorter than the internodes of the rachis: rachis sinuate and flattish; glumes stout, thick, about 8 mm long, strongly veined and scabrous, truncate, terminating in 3 awns about 25 mm long, the central one usually shorter: awns scabrous: lemma less firm in texture, glabrous, terminating in 2 or 3 very short unequal mucronate points: palea two-keeled membranous, scabrous on the keels: caryopsis ellipsoidal, somewhat acute at each end, 9 mm long and 3 mm broad, light brown with a prominent brush: upper spikelets rudimentary, the lemma having 3 awns, one of them being nearly as long as those of the glumes. In the terminal spikelet the awns may branch so as to appear like 7 awns to each glume.

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INHERITANCE IN NODAK AND KAHLA DURUM WHEAT CROSSES FOR RUST RESISTANCE, YIELD, AND QUALITY AT DICKINSON, NORTH DAKOTA[1]

J. ALLEN CLARK AND RALPH W. SMITH[2]

IMPROVEMENT IN DURUM WHEAT DESIRED

Breeding of durum wheats for resistance to stem rust and for yield and quality must be practiced if improvement in this class of wheat is to keep pace with the progress being made by similar means in the hard red spring wheats. This improvement in durum wheats must be made soon or the industry will suffer. The best durum varieties are not sufficiently resistant to stem rust and the resistant varieties do not have the desired quality for the manufacture of semolina and the edible pastes, such as macaroni. The improvement over Marquis in yield by such rust-resistant hard red spring wheats as Ceres, Marquillo, Hope, and other unnamed hybrid selections may soon cause a reduction of the acreage of durum wheat unless the price of durum increases and remains above that of hard red spring.

MATERIAL AND METHODS

In a breeding program for the improvement of durum wheats it seemed desirable to combine a high-yielding, rust-resistant variety with one of highest quality, although lacking in rust resistance and yield. The study of the inheritance of such quantitative characters as yield and quality necessitates careful methods of growing the hybrid material and the parent checks in order to obtain comparative results.

PARENT MATERIAL

The new rust-resistant and high-yielding Nodak variety, developed by selection at the Dickinson Substation, Dickinson, N. Dak., was chosen for crossing with Kahla, a high-quality variety but not resistant or high yielding. To show the comparative behavior of the two parent varieties, data from the plat experiments at the Dickinson Substation are given in Table 1.

The data show both varieties to possess certain advantages which, if combined in a new variety, should result in marked improvement over either parent.

[1]Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Received for publication October 4, 1928.

[2]Senior Agronomist in Charge, Western Wheat Investigations, and Associate Agronomist, respectively. The writers wish to express appreciation to Karl S. Quisenberry and John R. Hooker for assistance in these investigations.

TABLE 1.—*Annual and average stem-rust infection, crude-protein content, gasoline color value, and yield of Nodak and Kahla durum wheats grown in plat experiments at the Dickinson, N. Dak., substation during the four years, 1922 to 1925, inclusive.*

Variety and year	Stem rust infection %	Crude protein (N x 5.7) %	Gasoline color value	Yield per acre in bushels
		Nodak		
1922	4	12.2	1.43	34.9
1923	T	13.4	1.59	23.8
1924	T	10.0	1.63	21.0
1925	0	15.0	0.85	15.5
Average	1	12.7	1.38	23.8
		Kahla		
1922	5	14.4	2.22	29.0
1923	25	14.0	2.12	17.4
1924	1	11.8	2.20	17.8
1925	0	15.0	1.44	14.9
Average	8	13.8	2.00	19.8

NODAK

Nodak (C. I. No. 6519), which has been commercially grown since 1923, was developed from a plant selection of Kubanka and was first known as Kubanka No. 98. The history of its development was reported by Smith, Waldron, and Clark (3).[3] Nodak has yellowish glumes, is rust resistant, and high yielding, with fair protein content, but, as revealed by the gasoline color test, it lacks the yellow color desirable for the manufacture of semolina and the making of macaroni.

KAHLA

Kahla (C. I. No. 5529) is of Algerian origin and has been grown to a limited extent in Montana and North Dakota for several years as Black Durum, Algerian Durum, and under other names. Kahla has black glumes and, in varietal experiments at Dickinson, it has been a low-yielding variety and not resistant to stem rust. At the time this cross was made, however, Kahla had the highest gasoline color value of any of the durum varieties grown at the Dickinson Substation.

METHODS USED

The crosses, Nodak x Kahla and its reciprocal, were made in the summer of 1924 at the Dickinson Substation. The F_1 plants and

[3]Reference by number is to "Literature Cited," p. 1304.

an F_2 population were grown at that station in 1925 and 1926, respectively. A random population of 89 F_3 strains was grown in 1927 with parent checks alternating in every tenth row. The rows were 5 feet long with 25 kernels sown per row. Each F_3 strain and parent check was triplicated, making a nursery of 300 rows. At harvest time each of the rows was studied for stem-rust infection and notes were taken as to whether it was resistant, susceptible, or segregating. From each of the hybrid plants in a row one head was harvested and placed in an envelope. The remaining material was threshed and the yield was recorded on a row basis. The single heads from each plant were sent to Washington, D. C., where notes were taken on number of plants and glume color. These heads were then threshed and the yield for the triplicate rows of each F_3 strain and parent check was computed to a plant basis. Crude protein[4] and gasoline color[5] tests were made on the bulk sample of wheat from the three replications. The gasoline color tests were made by the rapid method described by Coleman and Christie (2) for determining the gasoline color value of wheat.

SEGREGATION OF CHARACTERS

The characters studied were glume color, stem-rust reaction, yield per plant, crude-protein content, and gasoline color value. The results of the studies follow in the order in which the characters are listed above.

GLUME COLOR

In common wheats glume color is most commonly classed as white and brown. Brown glumes usually are dominant over white in F_1 and in the F_2 generation segregate in the single genetic ratio of 3:1. In durum wheats the principal glume colors are white, yellowish, and black. The present cross is between yellowish-glumed and black-glumed varieties. The F_1 plants had black glumes. The segregation obtained in the F_2 generation is given in Table 2.

The F_2 data indicate a close fit to a 3:1 ratio with black glumes dominant to yellowish. The study was continued in the F_3 generation and the data obtained are given in Table 3.

TABLE 2.—*Segregation for glume color in the F_2 generation of 342 plants of reciprocal crosses of Nodak-Kahla durum wheats grown at Dickinson, N. Dak., in 1926.*

Cross	Number of F_1 plants	F_2 plants by glume color Black	Yellowish	Total	Deviation from 3:1 ratio	Probable error
Nodak x Kahla	12	262	80	342	5.5	5.4

[4]The crude protein tests were made by H. M. Joslin in the nitrogen laboratory of the Bureau of Chemistry and Soils under a cooperative agreement with the office of Cereal Crops and Diseases, Bureau of Plant Industry.

[5]The gasoline color tests were made by Alfred Christie, Jr., in the Research Laboratory of the Grain Division of the Bureau of Agricultural Economics.

TABLE 3.—*Breeding behavior for glume color in the F_3 generation of 89 F_2 families selected at random from Nodak-Kahla durum wheat crosses and grown at Dickinson, N. Dak., in 1927.*

F_2 classes and their breeding behavior in F_3	F_2 families Number	F_2 families Expected on 1:2:1 ratio	Number of F_3 plants by glume color: Black	Yellowish	Total	Deviation from 3:1 ratio	Probable error
		Glumes Black					
Black	22	22	772	—	772	—	—
Black and yellowish	49	45	1,380	472	1,852	9.00	12.6
		Glumes Yellowish					
Yellowish	18	22	—	662	662	—	—
Total	89	89	2,152	1,134	3,286		

The F_3 segregation in the heterozygous black-glumed group shows as close a fit to a 3:1 ratio as did the F_2, and the breeding behavior of the 89 families also is close to a 1:2:1 ratio $P = 0.59$. A single genetic factor for glume color thus is shown to be present, black glumes being dominant to yellowish.

STEM-RUST REACTION

No stem rust occurred on the F_1 and F_2 material of this cross grown at Dickinson, N. Dak., in 1925 and 1926. On the F_3 material in 1927 the infection was not heavy and notes were not taken on an individual plant basis. Sufficient rust was present, however, to determine the resistant strains similar to the Nodak parent, the susceptible strains similar to the Kahla parent, and the segregating strains. The reaction to stem-rust infection on the F_3 strains and parents in 1927 is shown in Table 4.

The data show susceptibility dominant to resistance. Only 3 of the 89 strains appeared to be homozygous for resistance, indicating that two or more genetic factors for rust reaction may be present. Selections were made of the resistant plants in the resistant and segregating F_3 strains. These were continued for testing further their rust resistance and other qualities.

TABLE 4.—*Reaction to stem-rust infection in the F_3 generation of 89 F_2 families from Nodak-Kahla durum wheat crosses grown at Dickinson, N. Dak., in 1927.*

Reaction to stem-rust infection	Number of F_3 strains and parent checks: Kahla	Nodak x Kahla	Nodak
Susceptible	5	73	–
Segregating	–	13	–
Resistant	–	3	6
Total	5	89	6

YIELD

In 1927 the average plant yield from the three replications of parents and F_3 strains was determined and the results are given in Table 5.

The data show the F_3 hybrid strains to average intermediate between the parents. Nodak considerably outyielded Kahla. The difference is 1.70 ± .23 grams and is significant. There were F_3 strains which exceeded the best Nodak checks for yield. These high-yielding strains are being continued in the F_4 for further study of yield and for making plant selections within them for other characters.

TABLE 5.—*Average plant yields of parent varieties and 89 F_3 strains of Nodak-Kahla durum wheat crosses grown at Dickinson, N. Dak., in 1927.*

Yield per plant in grams	Number of F_3 strains and parent checks: Nodak	Nodak x Kahla	Kahla
8.0	–	5	–
7.5	–	2	–
7.0	–	7	–
6.5	2	11	–
6.0	2	14	–
5.5	2	14	–
5.0	–	17	2
4.5	–	12	1
4.0	–	7	–
3.5	–	–	2
Total	6	89	5
Average and probable error	6.00±.11	5.66±.08	4.30±.20

CRUDE-PROTEIN CONTENT

The crude-protein content of the bulked grain from the three replications of the F_3 strains and parent checks was determined and the results are given in Table 6.

TABLE 6.—*Crude-protein content of parent varieties and 89 F_3 strains of the Nodak-Kahla durum wheat crosses grown at Dickinson, N. Dak., in 1927.*

Crude-protein content (N x 5.7, 13.5% moisture)	Number of F_3 strains and parent checks: Nodak	Nodak x Kahla	Kahla
16.0	–	1	–
15.5	–	9	–
15.0	1	14	–
14.5	3	29	1
14.0	2	19	3
13.5	–	12	1
13.0	–	3	–
12.5	–	2	–
Total	6	89	5
Average and probable error	14.42±.10	14.36±.05	14.00±.10

The data show Nodak to exceed Kahla slightly in protein content. The difference is 0.42 ± .14%, giving odds of about 22:1 that it is significant. The F_3 hybrids average intermediate between the parents, with an indication of transgressive segregation. The lack of numbers in the parent strains does not enable definite conclusions as to this. The results, however, have furnished a basis for continuation of the high protein strains from which plant selections will be made in the F_4 generation.

GASOLINE COLOR VALUE

The gasoline color value was suggested by Clark (1) as a measure which could be used for color quality in breeding durum wheats. The gasoline color test has been found reliable in measuring the amount of yellow carotinoid pigment and the colorimeter readings are more scientifically accurate than arbitrary scoring of semolina.

In the present work the gasoline color value of the bulked grain from the three replications of the F_3 strains and parent checks grown at Dickinson, N. Dak., in 1927, was obtained and the results are given in Table 7.

The data show Kahla to exceed Nodak significantly in average color value. The difference is 0.28 ± .04, and is significant. The hybrids were intermediate between the parents and here again transgressive segregation is indicated. The data furnished the desired basis for selecting strains of high color value for continued study and plant selection in the F_4 generation.

TABLE 7.—*Gasoline color value of parent varieties and 89 F_3 strains of the Nodak-Kahla durum wheat crosses grown at Dickinson, N. Dak., in 1927.*

Gasoline color value	Number of F_3 strains and parent checks		
	Kahla	Nodak x Kahla	Nodak
2.18	–	1	–
2.03	–	2	–
1.88	–	2	–
1.73	3	9	–
1.58	1	18	–
1.43	1	29	3
1.28	–	20	3
1.13	–	6	–
0.98	–	2	–
Total	5	89	6
Average and probable error	1.64±.04	1.46±.02	1.36±.02

CORRELATION OF CHARACTERS

The correlated inheritance of the quantitative characters of yield, crude-protein content, and gasoline color value have been studied in the F_3 generation.

YIELD AND PROTEIN CONTENT

The coefficient of correlation obtained for yield and protein content was positive, $r = + 0.139 \pm .070$, but was neither significant nor important.

YIELD AND GASOLINE COLOR VALUE

The correlation coefficient of yield and gasoline color value was negative, $r = - 0.184 \pm .069$, but also was not significant nor important.

PROTEIN CONTENT AND GASOLINE COLOR VALUE

The coefficient of correlation between crude-protein content and gasoline color value was found to be negative, $r = - 0.334 \pm .064$. This value is both significant and important. The correlation surface is given in Table 8.

The distribution of the data shown in Table 8 illustrates the negative relationship which existed between crude-protein content and gasoline color value in the hybrid material grown at Dickinson, N. Dak., in 1927. This is in agreement with results from different varieties shown by Clark (1) and indicates the necessity of giving consideration to both these quality factors, as well as to rust resistance and yield, in a breeding program with durum wheats.

TABLE 8.—*Correlation between crude-protein content and gasoline color value of 89 F_3 strains of Nodak-Kahla durum wheat crosses grown at Dickinson, N. Dak., in 1927.*

Crude-protein content	Gasoline color value									
%	0.98	1.13	1.28	1.43	1.58	1.73	1.88	2.03	2.18	Total
12.5	–	–	–	2	–	–	–	–	–	2
13.0	–	–	–	2	–	1	–	–	–	3
13.5	–	–	3	4	3	1	1	–	–	12
14.0	–	1	5	6	3	1	–	2	1	19
14.5	1	4	7	9	5	2	1	–	–	29
15.0	–	–	2	4	6	2	–	–	–	14
15.5	1	1	3	1	1	2	–	–	–	9
16.0	–	–	–	1	–	–	–	–	–	1
Total	2	6	20	29	18	9	2	2	1	89

$r = -0.334 \pm .064$

SUMMARY

Breeding durum wheats for resistance to stem rust, and with higher yield and quality, is becoming necessary. A cross was made between Nodak, a yellowish-glumed, rust-resistant, high-yielding variety, of only fair quality, and Kahla, a black-glumed, rust-susceptible, low-yielding but high-quality variety, and studied for the inheritance of these characters at the Dickinson, N. Dak., substation.

Glume color was found to be controlled by a single genetic factor, black being dominant to yellowish.

Susceptibility to stem rust was found to be dominant to resistance, with the indication of at least two genetic factors being involved.

Yield of F_3 plants was found intermediate between the parents with certain F_3 strains exceeding the yield of the best parent checks.

Crude-protein content for F_3 strains was intermediate in comparison with the parents, with an indication of transgressive inheritance beyond that of the parents for both high and low-protein content.

The gasoline color value of the F_3 strains also was intermediate between those of the parents, and transgressive inheritance was indicated for both high and low color.

The tests of crude-protein content and gasoline color value furnished a basis for selecting hybrid strains for high quality.

A significant and important negative correlation was found between crude-protein content and gasoline color value, indicating the necessity for giving consideration to both these quality factors, as well as to rust resistance and high yield, in a breeding program with durum wheats.

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EFFECT ON SOIL REACTION OF NITROGENOUS FERTILIZERS UNDER THE ANAEROBIC CONDITIONS OF RICE PRODUCTION[1]

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Fertilizer recommendations for soils in the different areas of the world devoted to the production of rice are very different. This is particularly true with regard to the form of nitrogen which should be used to secure the best yields. While the results from numerous experiments have been reported, the conclusions drawn have not harmonized and indicate that all factors controlling the availability of the nitrogen were probably not controlled. Unfortunately, in many of the experiments, conditions such as reaction, texture, structure, and previous cropping history were not recorded so that variations in results can not be explained as due to these factors.

The production of rice, because of the anaerobic condition developed after irrigation, requires a special type of agriculture in which the growth conditions are different from those of any other crop. Among the different factors which might affect the growth of rice that of reaction changes due to the forms of nitrogen used may be of considerable importance. The work reported in this paper was started in order to secure more information upon this subject.

With the exception of changes due to continued applications of sodium nitrate and ammonium sulfate, very little information regarding the reaction changes produced by nitrogenous fertilizers under either aerobic or anaerobic conditions is available. Pierre (11)[3] recently reported reaction changes due to a number of nitrogenous fertilizers in soil studies under aerobic conditions. He grouped the compounds into two classes, such as sodium nitrate, calcium nitrate, and calcium cyanamid which reduced the H-ion concentration, and ammonium sulfate, ammonium phosphate, Leunasalpeter, ammonium nitrate, and urea which increased the H-ion concentration in the order named.

PLAN OF EXPERIMENT

Equivalent amounts, 0.3 gram, of nitrogen in different compounds were added to 4-gallon earthenware jars containing 12 kilos of sand which was practically free from nitrogen. The forms of

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[3]Reference by number is to "Literature Cited," p. 1313.

nitrogen used were ammonium sulfate, urea, calcium nitrate, Ammophos, Leunasalpeter, sodium nitrate, calcium cyanamid, blood meal, cottonseed meal, and mixtures containing the nitrogen half as sodium nitrate and half as cottonseed meal and half as ammonium sulfate and half as cottonseed meal. Ammonium sulfate, sodium nitrate, and calcium nitrate were applied as C. P. salts. All others were applied from samples of material bought for fertilizers. In addition each jar received nitrogen-free nutrient solution and 100 cc of a water suspension made from a soil which had been planted to rice the previous year. The treatments were made in triplicate, two jars being seeded November 30, 1927, to rice and the third reserved to follow the rate of the changes in H-ion concentration. The cultures were irrigated with distilled water on January 6, 1928, when the plants were about 6 inches high so that the water stood about 2 inches deep over the sand. The samples for the H-ion determinations were secured by stirring the cultures thoroughly and letting them stand over night to establish equilibrium. Fifty cc of the supernatant liquid were then taken and dialyzed according to the method suggested by Pierre and Parker (10), and the reaction determined colorimetrically.

The results given in Table 1 for the rate of reaction changes are duplicate analyses from single jars, but the total changes produced may be compared with data to be presented later.

TABLE 1.—*Rate of reaction changes produced by different nitrogenous compounds in irrigated sand cultures.*

Source of nitrogen	Dates of sampling							
	Jan. 6	Jan. 13	Jan. 20	Jan. 27	Feb. 3	Feb. 10	Feb. 24	Mar. 16
	pH	pH	pH	pH	pH	pH	pH	pH
None	6.1	6.3	6.1	6.1	6.0	5.7	5.7	6.2
Ammonium sulfate	6.3	6.2	5.5	4.6	4.1	4.3	4.7	3.8
Calcium nitrate	6.5	6.6	6.5	6.3	6.1	6.1	6.6	6.8
Urea	6.8	6.5	6.5	6.0	5.2	5.4	6.1	6.5
Ammophos	6.3	6.2	5.3	4.8	4.2	4.2	5.3	5.3
Leunasalpeter	6.4	6.2	5.2	4.5	4.5	4.5	5.3	5.5
Sodium nitrate	6.3	6.7	6.5	6.3	6.2	6.3	6.3	6.7
Calcium cyanamid	6.9	6.8	6.6	6.5	6.1	6.2	6.2	6.6
Blood meal	6.7	6.6	6.1	5.7	5.6	5.9	5.5	5.8
Cottonseed meal	6.8	6.8	6.4	5.4	5.6	6.0	6.0	6.3
Cottonseed meal and sodium nitrate	6.9	6.3	6.1	5.9	6.2	6.1	6.4	6.8
Cottonseed meal and ammonium sulfate	6.7	6.4	6.3	5.4	4.4	4.6	5.2	5.2

CHANGES IN H-ION CONCENTRATION

The general trend of the results from the irrigated cultures agrees with the findings of Pierre (11) for aerobic conditions. Their significance will be discussed later with other results.

When the jars were irrigated the plants were rather uniform in regard to height and color. Within two weeks after flooding very marked differences began to appear in height and from then until one set was harvested only those fertilized with urea, cottonseed meal, and blood meal seemed to develop normally. The rice on all treatments became chlorotic about three weeks after flooding and remained that way for about four weeks when those having fair growth became green again.

While some investigators (4) might claim that the chlorotic condition was due to lack of soluble iron caused by decrease in H-ion concentration, the fact that it also occurred where there was an increase in H-ion concentration would tend to nullify such a claim. While some of the chlorosis may be due to lack of soluble iron, data to be presented in a later paper indicate that the chlorotic condition is largely due to a deficiency of available nitrogen. As the results from the uncropped irrigated cultures gave some indication as to the nature of the disturbance, one jar from each treatment was harvested February 15, 1928, the roots examined, and the H-ion concentration determined as previously described. The H-ion concentrations are given in Table 2.

TABLE 2.—*The H-ion concentration of irrigated sand cultures after rice fertilized with nitrogenous fertilizers.*

Fertilizer	pH
None	6.4
Ammonium sulfate	3.0
Calcium nitrate	7.6
Urea	5.6
Ammophos	4.1
Leunasalpeter	4.0
Sodium nitrate	8.2
Calcium cyanamid	7.0
Blood meal	6.2
Cotton seed meal	6.3
Cottonseed meal and sodium nitrate	7.0
Cottonseed meal and ammonium sulfate	4.4

The results of these determinations also agree with those of Pierre (11) in that calcium nitrate, sodium nitrate, and calcium cyanamid caused a reduction in H-ion concentration, while ammonium sulfate, Ammophos, Leunasalpeter, and urea produced an increase in H-ion concentration. In addition to the division into acid and alkaline groups, there is a possibility of a third group represented by blood

meal and cottonseed meal which may have very little affect on the H-ion concentration. The changes taking place in the H-ion concentration in this experiment are large because of the low buffer capacity of the sand. Under field conditions the H-ion concentrations reported would probably only appear after a number of applications of the materials given because the buffer capacity would prevent a too rapid change. The number of applications necessary to produce any material change in the H-ion concentration of the soil would depend upon the buffer capacity of the soil.

EFFECT OF H-ION CONCENTRATION ON GROWTH

According to some investigators, including Kelly (8) and Harrison (6), good results should be obtained with ammonium compounds or those producing ammonia under irrigated conditions. Unless other factors affected the results, the best yields should have been obtained by the ammoniates and those producing ammonia in this experiment. That some other factor besides the form of nitrogen was affecting the crop yield can be seen from the results in Table 3.

TABLE 3.—*Effect of reaction changes on the growth of rice.*

Source of nitrogen	Weight of tops of oven-dry matter in grams: Harvested Feb. 15	Weight of tops of oven-dry matter in grams: Harvested April 2
None	0.3	0.5
Ammonium sulfate	2.3	5.0
Calcium nitrate	0.7	0.8
Urea	8.3	18.5
Ammophos	2.5	6.7
Leunasalpeter	3.2	13.1
Sodium nitrate	0.6	0.6
Calcium cyanamid	1.0	1.5
Blood meal	6.1	10.5
Cottonseed meal	6.6	12.3
Cottonseed meal and sodium nitrate	1.5	1.9
Cottonseed meal and ammonium sulfate	4.2	11.5

The yields show that only in those cultures in which the changes in H-ion concentration were small was the growth anything like normal.

The yields from the different treatments seem to be affected inversely to the change in H-ion concentration. For example, the pH of the sand fertilized with calcium cyanamid, calcium nitrate, and sodium nitrate were, respectively, pH 7.0, pH 7.6, and pH 8.2, while the yields of dry matter were 1.0, 0.7, and 0.6 gram, respectively. The compounds causing an increase in H-ion concentration can be grouped in a similar manner into ammonium sulfate, Leunasalpeter, Ammophos, and urea, producing a pH of 3.0, 4.0, 4.1, and 5.6,

respectively, with yields of dry matter of 2.3, 3.2, 2.5, and 8.3 grams, respectively. Cottonseed meal and blood meal had practically no affect on the H-ion concentration and the yield of dry matter from these treatments was very good, being 6.6 grams and 6.1 grams, respectively. The results from using a half and half mixture of an organic and inorganic source of nitrogen furnish additional proof that the changes in H-ion concentration are being produced by the nitrogenous fertilizers. A comparison of the change in H-ion concentration produced by the mixture of cottonseed meal and sodium nitrate with that produced by sodium nitrate shows it to be only about half as great, while the amount of dry matter produced is twice as much. A similar comparison of cottonseed meal and ammonium sulfate with ammonium sulfate alone gives similar results, except that the change is to increase the H-ion concentration.

The results seem to indicate that a decrease of H-ion concentration until the media has a neutral or alkaline reaction seems to be more harmful than an increase of the same proportion towards making the H-ion concentration greater. For example, a change from pH 6.3 to pH 3.0 in the case of ammonium sulfate gave a yield of 2.3 grams dry matter, while a change from pH 6.3 to pH 7.0 with calcium cyanamid and pH 7.6 with calcium nitrate gave yields of only 1.0 gram and 0.7 gram, respectively. Some of the sensitiveness to an alkaline reaction may be due to the effect the changes in H-ion concentration have on chemical processes in the soil. The extent to which the chemical processes may be affected by an increase or decrease in H-ion concentration has been left for future study.

The effect which the change in H-ion concentration had on the growth is also shown by the condition of the roots at the time of harvest. The roots from the no-treatment jar were short, due to lack of nitrogen, but were very healthy. The roots from the urea, cottonseed meal, and blood meal were large and well developed. The ones from the cottonseed meal and sodium nitrate and ammonium sulfate mixtures were only fairly well developed and showed some brown discoloration. The roots from all of the other treatments were short, poorly developed, and had some brown discoloration which gave evidence of injury due to the reaction of the media.

As a further check upon the effect of H-ion concentration, sufficient acid or alkali in amounts necessary in dilute solution was added to bring the H-ion concentration in the range from pH 6.0 to pH 6.5. The plants were harvested April 2, 1928, and their dry weights determined. The results (Table 3) showed that where the roots had not been too badly injured the plants partially recovered from the

early injury due to the H-ion concentration and made good growth. However, in the ammonium sulfate, calcium nitrate, Ammophos, sodium nitrate, calcium cyanamid, and cottonseed meal and sodium nitrate treatments the injury had been so severe that the plants did not recover.

The principal nitrate fertilizers, sodium nitrate and calcium nitrate, are physiologically basic fertilizers. The same thing may be said of calcium cyanamid. On the other hand, the ammoniates are acid-producing fertilizers. The organic nitrogenous compounds have very little effect upon the soil reaction. In view of the large changes produced in the H-ion concentration by some nitrogenous fertilizers and the apparent sensitiveness of rice to changes produced by physiologically basic fertilizers, it seems very probable that some of the differences in recommendations of nitrogenous fertilizers for rice may have resulted from failure to control the soil reaction in the fertilizer experiments made to determine the best materials to use.

CAUSES OF REACTION CHANGES

Whether or not the changes in H-ion concentration are induced by the same factors under normal and under irrigated conditions is of interest because of the great difference in the processes involved. Under normal conditions biological activity is largely of an aerobic nature, while under irrigated conditions it is largely anaerobic, although in the latter case aerobic processes are involved up to the time of irrigation.

It has been fairly well established from the work of Frear (3) Wheeler (13), Ames and Schollenberger (1), Page (9), and Pierre (11) that the development of acidity from ammonium sulfate and other ammonium fertilizers under aerobic conditions arises from nitrification and base exchange reactions rather than from the direct utilization of the ammonia by plants. However, there is the possibility that the assimilation of ammonia by certain plants, such as has been reported for rice by Stubbs, Dodson, and Brown (12) and by Fraps (2), may cause an increase in the H-ion concentration of the medium upon which it is grown. As far as the writer knows there is no literature available upon the increase of H-ion concentration due to direct assimilation of ammonia by plants under aerobic conditions.

The conditions existing in soils where rice is grown by irrigation are directly opposite to those mentioned above. In this case the biological processes which take place after irrigation are largely anaerobic, although up to the time of flooding the processes are aerobic and

some nitrification may take place before flooding. The nitrogen compounds under anaerobic conditions according to Greaves (5) may be affected in a number of ways. The nitrates may be reduced to ammonia or free nitrogen, a loss may take place during the breaking down of complex proteins into simpler form, and the nitrates or ammonium compounds may be transformed into more complex proteins. The adsorption of ammonia ion in excess of the sulfate ion from ammonium sulfate by soils and sand as reported by Wolkoff (14) would also in all probability take place under irrigated as well as under aerobic conditions. It is the last two factors which apparently are most active in causing an increase in the H-ion concentration under anaerobic conditions.

No determinations of the adsorption capacity of the sand for ammonia was made because it was believed that due to its coarse ness the capacity for adsorption was rather low. The assimilation of nitrogen by bacteria at least in the one experiment played a very important part in producing an increase in the H-ion concentration. In every test when an ammonium compound was used there was an increase in the H-ion concentration. With the exception of ammonium sulfate, there was a gradual increase in H-ion concentration up to a certain concentration when it began to decrease again. In all cases the change from increasing to decreasing of the H-ion concentration took place at the same time. The decrease in H-ion concentration may be due to the completion of one cycle in the life of the organisms with a subsequent liberation of ammonia from their bodies.

A comparison of the reaction of the cropped jars with the reaction of similar jars of the uncropped series shows the H-ion concentration to be much greater where plants were grown. The reaction for ammonium sulfate in the cropped series was pH 3.0, while in the uncropped it was pH 3.8. For urea it was pH 4.1 and pH 5.3, respectively, for the cropped and uncropped jars. The assimilation of ammonia evidently was an important factor in producing an increase in the H-ion concentration.

The development of alkaline reaction due to the so-called physiologically basic fertilizers, such as sodium nitrate and calcium cyanamid, arises from an entirely different set of conditions than those producing an increase in H-ion concentration. The information so far reported from soil studies gives no evidence that the soil plays any important part in reducing the H-ion concentration when physiologically basic fertilizers are used. It must be assumed, therefore, that the plant plays a major part in the reduction of H-ion concen-

tration when fertilized with physiologically basic fertilizers. There are two assumptions which may be used in explanation, that of the early investigators in which it was believed that the plants take up the nitrate ion and leave the sodium ion; and that based upon more recent work (7) which indicates that the plants take up compounds rather than ions or that if ionization does play any part it is in an exchange of ions between the solution and roots of the plant

The factors causing a decrease in H-ion concentration under anaerobic conditions due to physiologically basic fertilizers are somewhat similar to those under aerobic condition. However, in addition to the assimilation of nitrogen by plants leaving a basic residue, the reduction of nitrates to either ammonia or free nitrogen, depending upon environmental factors, will accomplish the same thing under anaerobic conditions. If ammonia was produced, the H-ion concentration would be decreased just twice as fast as if free nitrogen were produced. The changes due to this latter process may be rather large under some conditions, although it is doubtful if it ever approaches the degree of that caused by the assimilation of nitrogen by plants.

The slight change produced by the third group of fertilizers may be due to the liberation of sufficient basic material by decomposition to neutralize any acids which may be formed. However, in most cases ammonia is the only form of nitrogen produced from organic matter under anaerobic conditions and which, upon assimilation by plants, leaves no acid or alkaline residue in the soil.

SUMMARY

Experiments are reported in which the changes of H-ion concentration caused by application of different nitrogenous fertilizers were studied under conditions similar to those existing in rice fields. A study was also made of the effect these changes had upon the growth of rice.

The nitrogenous fertilizers may be divided according to their effect on the H-ion concentration into three groups, *viz.*, (a) acid-producing, (b) alkaline-producing, and (c) those having practically no effect on the H-ion concentration. The groups arranged in order of largest to smallest change are as follows: (a) *acid-producing*, ammonium sulfate, Leunasalpeter, Ammophos, and urea; (b) *alkaline-producing*, sodium nitrate, calcium nitrate, and calcium cyanamid; and (c) *practically no change*, cottonseed meal and blood meal.

Changes in H-ion concentration due to applications of ammonium sulfate, Ammophos, Leunasalpeter, calcium nitrate, sodium nitrate, and calcium cyanamid greatly affected plant growth. The de-

crease in H-ion concentration caused by the latter three was more harmful than the increase caused by the first three, even though the increases were from two to three times greater than the decreases. Failure to control changes in H-ion concentration in studies concerning the availability of nitrogenous fertilizers may lead to erroneous interpretations of the results.

The changes in H-ion concentration under the conditions studied were due largely to assimilation of the nitrogen by plants and bacteria. Some of the change may have been due to the liberation of elemental nitrogen by denitrifying bacteria.

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LODGING IN SELFED LINES OF MAIZE AND IN F_1 CROSSES[1]

H. K. HAYES AND C. K. McCLELLAND[2]

During the season of 1928, there was an opportunity to study the comparative ability to stand up of selfed lines of maize and F_1 crosses between them. At about silking time a severe wind and rain storm occurred. A casual observation indicated rather wide differences in the extent of lodging among the different strains. The material available furnished an unusually good chance to determine the extent to which the degree of lodging of F_1 crosses could be predicted upon the basis of a knowledge of the relative ability of the parental selfed lines to withstand lodging.

MATERIAL AND METHODS

The material available consisted of selected selfed lines of Minnesota No. 13, Rustler, and Northwestern Dent which were being used as parental strains for the purpose of testing their ability to combine and produce high-yielding F_1 crosses. The selected selfed strains consisted of 7 strains of Northwestern Dent, 12 of Minnesota No. 13, and 14 of Rustler. The strains had been selfed from four to ten years. It was planned to test the comparative desirability of F_1 combinations of strains originating from the same commercial variety.

The selfed lines and F_1 crosses were grown on the same field and were planted in two systematically distributed single-row plats of 12 hills each. The crosses were bordered by rows planted from commercial seed of the variety from which the strains were produced. The selfed lines were planted in alternate rows with a bulk strain obtained by planting a mixture of selfed seed of strains of corn originating from the same variety. This was done so that, as far as possible, all F_1 crosses or selfed lines which originated from the same variety would be under similar competitive conditions. Counts were made of the stalks, noting the number erect, the number inclined 20 degrees from the perpendicular, the number inclined 40 degrees, and the number inclined 60 degrees or more. A very few stalks here and there were inclined more than 60 degrees or flat, but the number did not justify the carrying of another division, as only in a very few instances would the lodging index have been changed and then but slightly.

[1]Contribution from the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St. Paul, Minn. Published with the approval of the Director as Journal Series Paper No. 808. Received for publication October 11, 1928.

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The lodging index was determined by multiplying the number of stalks of each group by the angle of inclination of that group and dividing the sum by the number of stalks in the row, thus:

No. of Stalks	Angle	Product
10	0°	0
20	20°	400
6	40°	240
0	60°	0
36		640

$640 \div 36 = 17.8$, or the lodging index

After determining the index, the average for the strain or cross was obtained by averaging the results of the two systematically distributed plats.

The reliability of the results was determined by correlating the lodging index of the first and second series of plats, while the extent to which the degree of lodging was dependent upon inherited differences was deduced from correlation coefficients in which the index of lodging of the parents and their F_1 crosses was compared.

EXPERIMENTAL RESULTS

A measure of the extent to which the computed lodging index of one series of strains furnished relevant information regarding the lodging of a second series of the same strains was determined from the correlation between the lodging index of the first and second series of plats. These results are given in Table 1.

TABLE 1.—*Correlation between lodging index in first and second series.*

Variety	Breeding	Number of lines	Correlation coefficient*
N. W. Dent	Selfed lines	7	$+0.57 \pm 0.19$
Minn. No. 13	Selfed lines	12	$+0.69 \pm 0.11$
Rustler	Selfed lines	14	$+0.86 \pm 0.05$
N. W. Dent	F_1 crosses	22	$+0.78 \pm 0.06$
Minn. No. 13	F_1 crosses	36	$+0.78 \pm 0.04$
Rustler	F_1 crosses	32	$+0.78 \pm 0.05$

*The formula used for P. E. of r was $\pm \frac{.6745(1-r^2)}{\sqrt{n-1}}$ as recommended by Fisher.

When it is remembered that only 12 hills were available to use in the determination of the lodging index, it appears that lodging differences in these studies are dependent to a considerable extent upon inherited factors.

The type of results obtained may be illustrated by studying a particular series of crosses. Among the Minnesota No. 13 strains, C 49 excelled in strength of stalk with a lodging index of 15.5. The results of certain F_1 crosses between C49 and other strains in comparison with their parents are given in Table 2.

TABLE 2.—*Comparison of lodging index of selfed lines and their F_1 crosses.*

The F_1 cross	Lodging index C49 parent	Lodging index Other parent	Lodging index F_1 cross
C41 x C49	15.5	33.8	21.5
C42 x C49	15.5	29.8	23.1
C43 x C49	15.5	40.0	28.6
C45 x C49	15.5	30.9	14.6
C46 x C49	15.5	18.7	14.5
C47 x C49	15.5	25.3	14.1
C48 x C49	15.5	18.6	14.5
C49 x C50	15.5	38.0	28.0

These results are representative of others obtained. In crosses between lines which differ widely in lodging index, the F_1 was, as a rule, of intermediate type. Illustrations of such crosses are C41 x C49, C42 x C49, C43 x C49, and C49 x C50. In one case, where the parents, C45 and C49, differed widely in standing ability, the F_1 resembled the non-lodging parent. There were three cases, *viz.*, C46 x C49, C47 x C49, and C48 x C49, where both parents were relatively low in lodging index. The F_1 crosses in all three cases were slightly more erect than either parent.

A measure of the extent of resemblance in lodging index of parental selfed lines and their F_1 crosses can be obtained by the use of correlation coefficients. Table 3 gives the correlation between F_1 crosses and their lesser lodging parent, Table 4 between F_1 crosses and their greater lodging parent, and Table 5 between F_1 crosses and the average of their parents.

TABLE 3—*Correlation between lodging indices of the lesser lodging parental selfed line and of F_1 crosses.*

Variety	Number of comparisons	Correlation coefficient
N. W. Dent	23	$+0.72 \pm 0.07$
Minn. No. 13	38	$+0.64 \pm 0.07$
Rustler	28	$+0.60 \pm 0.08$

TABLE 4.—*Correlation between lodging indices of the greater lodging parental selfed line and of F_1 crosses.*

Variety	Number of comparisons	Correlation coefficient
N. W. Dent	23	$+0.49 \pm 0.11$
Minn. No. 13	38	$+0.68 \pm 0.06$
Rustler	28	$+0.53 \pm 0.09$

TABLE 5.—*Correlation between average lodging indices of the selfed lines used as parents and of their F_1 crosses.*

Variety	Number of comparisons	Correlation coefficient
N. W. Dent	23	$+0.72 \pm 0.07$
Minn. No. 13	38	$+0.77 \pm 0.05$
Rustler	28	$+0.65 \pm 0.07$

On an average, the correlation was slightly higher between the lodging index of the F_1 crosses and their lesser lodging parent than for the F_1 crosses and their greater lodging parent, although the difference was of little mathematical significance in any case. The coefficients were slightly higher on an average for the correlation between the average of the parents with the F_1 crosses than where the cross was compared with either the greater or lesser lodging parent. This may have been a result of the use of four plats to obtain a parental average instead of two plats which was the number used when the F_1 was correlated with only one of its parents.

SUMMARY

1. A severe wind and rain storm at about silking time gave an unusual opportunity to study the extent to which lodging of F_1 corn crosses could be predicted on the basis of a knowledge of comparative ability of parental selfed lines to withstand lodging.

2. Where the parents were widely different in ability to withstand lodging, the F_1 was, in general, of intermediate habit, although there were some exceptions to this rule. When both parents had low lodging indices, the F_1 cross was also low and, when both parents had high lodging indices, the F_1 crosses lodged severely, as a rule.

3. The extent of agreement between parental selfed lines and their F_1 crosses was deduced from correlation coefficients. The three correlation coefficients for the comparison of lodging of the average of the parents and their F_1 crosses in three different varieties were $+ 0.72 \pm .07$, $+ 0.77 \pm .05$, and $+ 0.65 \pm .07$, respectively, which proves that ability to withstand lodging was dependent, to a considerable extent, on inherited differences.

REGISTRATION OF IMPROVED WHEAT VARIETIES, III[1]

J. ALLEN CLARK, J. H. PARKER, AND L. R. WALDRON[2]

This paper is the report of the 1927–28 Sub-committee on Wheat of the American Society of Agronomy for registering new varieties on the basis of performance.

Applications for the registration of additional wheat varieties have been requested by the committee. Those which have been received and approved are here registered as follows:

Varietal Name	*Registration No.*
Oro	259
Garnet	260
Reward	261
Nabob	262

The origin and performance which constitute the basis for registering these varieties are given below.

ORO—REG. No. 259

Oro (C. I. No. 8220) was developed at the Sherman County Branch Station, Moro, Oregon, as a pure-line selection and was first called Turkey 889–5. The selection was made at the Moro Station in 1921. Seed of the variety was first distributed for commercial growing in 1927. D. E. Stephens, Superintendent of the Moro Station, applied for the registration of Oro.

It has been in the regular replicated nursery experiments at Moro for six years and in plat experiments for three years. It also has been tested in a number of cooperative farm nurseries in Oregon from three to five years, and in plat experiments at several experiment stations in other states in 1928.

Oro differs from Turkey in having a shorter and blockier spike, and taller and stiffer straw. Oro also is resistant to bunt or stinking smut, is winterhardy, and of high quality for breadmaking. The comparative yield data of Oro and Kharkof winter wheats are shown in Table 1.

[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Department of Agriculture, and the American Society of Agronomy. Received for publication, November 10, 1928.

[2]Senior Agronomist in Charge of Western Wheat Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.; Professor of Crop Improvement, Kansas Agricultural College, Manhattan, Kans.; and Plant Breeder, North Dakota Agricultural Experiment Station, Fargo, N. Dak., respectively; members of 1926–27 Sub-committee of the American Society of Agronomy for the Registration of Wheat Varieties.

TABLE 1.—*Comparative yield data of Oro and Kharkof winter wheats in nursery and plat experiments, 1923–28.*

Station	Yield in bushels per acre						
	1923	1924	1925	1926	1927	1928	Average
			Nursery Experiments				
Moro, Oreg.							
Oro	45.0	23.2	17.4	20.8	29.0	29.5	27.5
Kharkof	35.6	18.5	22.4	21.6	30.7	29.4	26.4
Pendleton, Oreg.							
Oro	—	39.1	33.1	36.5	29.8	33.4	34.4
Kharkof	—	36.5	30.3	36.5	37.9	34.3	35.1
Wasco Co. Oreg.							
Oro	—	35.5	52.5	19.9	21.2	12.5	28.3
Kharkof	—	35.4	44.8	18.7	20.1	15.6	26.9
Eightmile, Oreg.							
Oro	—	—	—	17.0	21.0	25.3	21.1
Kharkof	—	—	—	18.4	21.5	24.5	21.5
Lexington, Oreg.							
Oro	—	—	—	22.1	25.3	22.7	23.4
Kharkof	—	—	—	19.9	29.8	20.6	23.4
Kent, Oreg.							
Oro	—	—	—	4.7	36.7	15.0	18.8
Kharkof	—	—	—	5.2	37.8	14.8	19.3
			Plat Experiments				
Moro, Oreg.							
Oro	—	—	—	27.6	39.5	37.0	34.7
Kharkof	—	—	—	27.0	37.9	40.7	35.2
Manhattan, Kans.							
Oro	—	—	—	—	—	46.4	—
Kharkof	—	—	—	—	—	45.5	—
Hays, Kans.							
Oro	—	—	—	—	—	41.2	—
Kharkof	—	—	—	—	—	40.2	—
North Platte, Neb.							
Oro	—	—	—	—	—	45.5	—
Kharkof	—	—	—	—	—	44.5	—
Havre, Mont.							
Oro	—	—	—	—	—	41.7	—
Karmont	—	—	—	—	—	38.2	—

GARNET—REG. No. 260

Garnet (Ottawa No. 652, C. I. No. 8181) was produced from a hybrid between Preston A (female) and Riga M (male) made in 1905 by Chas. E. Saunders, then Dominion Cerealist. It was first included in the varietal experiments at the Central Experimental Farm, Ottawa, in 1914, and at the Dominion Experimental Farms throughout western Canada in 1919. In 1926 it was introduced for commercial growing by L. H. Newman, present Dominion Cerealist, who applied for its registration.

Table 2.—*Annual and average yields in bushels per acre of Garnet, Marquis, and Reward wheats grown at 13 experiment stations in Canada during three or more of the five years from 1923 to 1927, inclusive.*

Farm	Garnet						Marquis						Reward					
	1923	1924	1925	1926	1927	Average	1923	1924	1925	1926	1927	Average	1923	1924	1925	1926	1927	Average
Ottawa, Ont.	44.8	55.0	33.4	41.1	46.6	44.2	45.5	48.0	34.6	39.3	45.7	42.6	35.2	43.0	31.7	37.5	47.5	39.0
Brandon, Man.	28.5	45.7	28.7	25.1	20.8	29.7	28.1	43.7	36.7	24.8	32.3	33.1	31.3	44.5	32.8	22.7	25.4	31.3
Indian Head, Sask.	29.0	13.0	48.8	57.5	30.0	35.7	26.7	19.6	45.8	49.2	41.1	36.5	31.3	12.2	41.9	45.9	19.1	30.1
Swift Current, Sask.	——	26.7	26.5	21.0	39.1	28.3	——	31.2	23.3	23.9	39.3	29.4	——	23.9	22.1	21.9	34.4	25.6
Scott, Sask.	——	6.9	38.4	31.0	44.0	30.1	——	9.8	33.7	24.3	49.0	29.2	——	9.2	36.4	28.0	39.0	28.2
Rosthern, Sask.	44.0	18.3	42.5	20.0	34.0	31.8	37.0	17.7	55.0	18.5	31.5	31.9	24.5	12.7	36.0	20.9	33.7	25 5
Lacombe, Alta.	61.3	5.7	43.1	48.8	47.7	41.3	57.5	9.0	52.8	46.5	40.6	41.3	46.7	5.0	35.5	45.0	40.9	34.6
Lethbridge, Alta.	——	21.0	21.7	24.4	18.8	21.7	——	18.3	21.6	38.1	26.7	26.2	——	14.8	22.8	23.9	19.8	20.3
Fort Vermilion, Alta.	——	23.0	44.0	40.7	40.0	36.9	——	33.0	48.0	47.3	49.0	44.3	——	33.0	39.0	43.3	56.0	42.8
Beaverlodge, Alta.	34.6	18.9	23.9	55.8	53.4	37.3	36.1	19.0	24.9	58.7	50.9	37.9	31.6	14.5	28.9	62.5	46.8	36.9
Morden, Man.	——	40.0	33.6	32.9	40.0	36.6	——	56.6	35.2	36.9	33.6	40.6	——	36.5	40.0	37.2	39.4	38.3
Ste. Anne de la Pocatiere, P. Q.	——	——	33.3	39.1	43.6	38.7	——	——	37.2	36.1	42.0	38.4	——	——	35.0	41.7	39.8	38.8
Nappan, N. S.	——	37.8	44.2	39.6	16.0	34.4	——	35.1	25.2	24.8	13.1	24.6	——	35.6	28.7	32.7	10.3	26.8
Average of 57 station years						34.5						35.8						32.1

The distinct advantage of Garnet is its early maturity, being 8 to 10 days earlier than Marquis. Garnet also yields well, has good strength of straw, and is of fair quality. It is awnletted and has white glabrous glumes and hard red kernels. Garnet has been tested for 15 years at Ottawa and at Dominion branch farms. Yield results during the five-year period from 1923 to 1927 in comparison with Marquis and Reward are given in Table 2. Further information on Garnet wheat will be found in a recent publication by Newman and Whiteside.[3]

REWARD—REG. No. 261

Reward (Ottawa No. 135, C. I. 8182) was produced from a Marquis (female) x Prelude (male) cross made in 1911, by Chas. E. Saunders. It has been tested at the Dominion experimental farms and stations throughout Canada for the past seven years. It was first distributed for commercial growing in 1927 by L. H. Newman, Dominion Cerealist, who applied for its registration.

The advantages of Reward are its early maturity, some degree of rust resistance, very large plump kernels of high quality, and a good show wheat. Reward is awnletted, with white pubescent glumes and hard red kernels. Yield results during the five-year period from 1923 to 1927 in comparison with Marquis and Garnet are shown in Table 2.

NABOB—REG. No. 262

Nabob (C. I. No. 8869) was developed at the Ohio Agricultural Experiment Station, Wooster, Ohio, as a pure-line selection from Nigger. The selection was made in 1918 by L. E. Thatcher, who applied for its registration. Seed of the variety was distributed for commercial growing in 1928.

TABLE 3.—*Yield comparisons of Nabob, Nigger, and Trumbull wheats in plat tests at Wooster, Ohio, for the past five years.*

Variety	Yield in bushels per acre					
	1924	1925	1926	1927	1928	Average
Nabob	35.3	35.3	52.5	49.8	38.5	42.3
Nigger	35.0	34.2	48.7	44.6	33.5	39.2
Trumbull	29.8	35.7	56.3	45.7	32.8	40.5

Nabob is awned and has white, glabrous glumes and midsized, semi-hard red kernels. Its superior characters are high yield, early maturity, winter hardiness, semi-resistance to bunt, and good qual-

[3]Newman, L. H., and Whiteside, A. G. O. Garnet wheat. Dom. of Canada, Dept. Agr. Bul. 83.

ity. Nabob has been under experiment for 10 years at the Ohio Station, sub-stations, and county experiment farms. The yield results in comparison with Nigger and Trumbull from plat experiments at Wooster during the past five years are shown in Table 3.

Further information about Nabob will be found in the last annual report of the Ohio Experiment Station.[4]

[4]Ohio Agr. Exp. Sta. Bul. 417:16. 1926–27.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, III[1]

T. R. STANTON, H. H. LOVE, AND E. F. GAINES[2]

The first list of registered varieties and strains of oats was published in 1926 and a second list was published in 1927.[3]

In the current year an additional new and improved strain has been submitted and approved for registration. As in some cases in previous years, the oat submitted for registration represents a physiological strain of a certain standard variety. It is as follows:

Group and Varietal Name	Registration No.
Spring Oats	
Early Yellow:	
Iogold	72

The description and record of this variety, on which approval for registration is based, are presented herewith for the benefit of those interested in improved oats.

IOGOLD—REG. No. 72

Iogold (C. I. No. 2329) was originated in 1906 as a pure-line selection (Iowa No. 109) from the Kherson variety. The plant selection was made by L. C. Burnett and subsequently developed by the Iowa Agricultural Experiment Station, in cooperation with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Iogold was first distributed to farmers of Iowa in the spring of 1927 by the Farm Crops Section of the Iowa Agricultural Experiment Station. It is a typical Kherson strain with yellow kernels. The superior characters of Iogold are stiffness

[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Department of Agriculture, and the American Society of Agronomy. Received for publication November 10, 1928.

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[3]STANTON, T. R., GRIFFEE, FRED, and ETHERIDGE, W. C. Registration of varieties and strains of oats. Jour. Amer. Soc. Agron., 18: 935-947. 1926.

————, LOVE, H. H., and DOWN, E. E. Registration of varieties and strains of oats, II. Jour. Amer. Soc. Agron, 19: 1031-1037. 1927.

of straw, high yield of grain, and resistance to stem rust. Iogold has been tested in field plats by the Iowa Agricultural Experiment Station at Ames since 1916. The annual and average acre yields of Iogold as compared with Kherson, the parent variety, and with Albion, Richland, and Iowar, improved registered varieties, during the 10-year period from 1916 to 1919, inclusive, and from 1921 to 1926, inclusive, at Ames, are shown in Table 1. The plats of Iowar were destroyed by floods in 1919 and no data were obtained on any varieties in 1920.

TABLE 1.—*Comparison of Iogold with other oat varieties at Ames, Iowa.*

	Variety and yield in bushels per acre				
Year	Kherson (standard)	Albion (Iowa No. 103)	Richland (Iowa No. 105)	Iowar	Iogold (new)
1916	53.8	46.1	53.6	56.7	57.3
1917	65.0	73.7	64.3	57.5	72.5
1918	62.5	48.7	55.6	62.5	61.2
1919	41.9	32.2	47.5	—	51.6
1921	25.9	37.4	37.2	41.2	35.9
1922	67.1	58.7	65.0	60.6	70.3
1923	78.7	68.7	78.1	87.8	80.3
1924	67.8	85.6	82.2	80.3	84.1
1925	56.9	49.6	53.9	56.2	55.6
1926	65.0	77.2	73.7	75.6	70.6
Average:					
1916–1919 and 1921–1926	58.5	57.8	61.1	—	63.9
1916–1918 and 1921–1926	60.4	60.7	62.6	64.3	65.3

The average yields of Iogold and other varieties in acre plats on 77 Iowa farms in 1927 are shown in Table 2.

TABLE 2.—*Farm tests of Iogold and other oat varieties in Iowa in 1927.*

Varieties compared with Iogold	Number of tests for each variety	Number of tests in favor of		Average yield in bushels per acre		
		Iogold	Home variety	Iogold	Home variety	Difference
Richland (Iowa No. 105)	29	16	13	54.7	56.6	—1.9
Albion (Iowa No. 103)	10	4	6	44.6	46.4	—1.8
Iowar	15	9	6	50.4	48.1	+2.3
Kherson	5	4	1	52.3	47.5	+4.8
Iogren	6	6	0	39.9	33.0	+6.9
Miscellaneous	12	11	1	46.7	37.8	+8.9
Summary	77	50	27	50.0	48.3	+1.7
Per cent	100	65	35			

There was a decided demand for seed of Iogold oat in the spring of 1928. The variety undoubtedly will replace Richland (Iowa No. 105) to some extent, especially where a similar but taller variety is desired. Iogold also should prove a valuable variety for use in breeding other stem-rust-resistant oats by hybridization. For further information on Iogold see Burnett.[4]

[4]BURNETT, L. C. Iogold oats. Iowa Agr. Exp. Sta. Bul. 247: 186–198. 1928.

BARLEY VARIETIES REGISTERED, II[1]

H. V. HARLAN, R. G. WIGGANS, AND L. H. NEWMAN[2]

The two varieties of barley submitted for registration in the past year are both smooth-awned and both were originated at the University of Minnesota. In common with all other smooth-awned forms which have been produced in the United States, these varieties owe their smoothness to an original introduction now known as Lion. This smooth-awned parent was first used in the cooperative breeding experiments between the University of Minnesota and the United States Department of Agriculture. The smooth-awned parent used in the cross from which these varieties were originated was a smooth-awned segregate of the Manchuria type from an earlier cross. The F_2 and subsequent generations of the later crosses were grown by the Plant Genetic and Plant Pathology Sections of the Minnesota Agricultural Experiment Station in a special disease nursery at University Farm, St. Paul. The Velvet and Glabron selections were made under these conditions.

VELVET—REG. No. 4 (C. I. No. 4252; MINN. No. 447)

Velvet was the first smooth-awned six-rowed variety distributed in the Mississippi Valley and has been more widely tested than Glabron. The results of the tests in Minnesota are presented in Tables 1, 2, 3, and 4. It is partly on its comparison with the well-known Manchuria, Minn. No. 184, that advance registry is asked. Even if the yield were not so favorable as it happens to be, there still would be justification in that a smooth-awned barley possesses agricultural advantages for which a certain amount of yield could be sacrificed.

GLABRON—REG. No. 5 (C. I. No. 4577; MINN. No. 445)

Glabron probably is superior to Velvet under many conditions. The average yields reported in the accompanying tables are not widely different, but such differences as do occur are in favor of this variety. Its stiffer straw probably is of more importance than the actual difference in yield.

[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Department of Agriculture, and the American Society of Agronomy. Received for publication November 10, 1928.

[2]Principal Agronomist in Charge of Barley Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture; Assistant Professor of Plant Breeding, Cornell University, Ithaca, N. Y.; and Dominion Cerealist, Dominion of Canada Experimental Farms, Ottawa, Canada, respectively. Members of the 1928 Sub-committee of the American Society of Agronomy for the Registration of Barley Varieties.

TABLE 1.—*Reaction to Helminthosporium sativum.**

Variety	Percentage reaction to *H. sativum* 1921	1922	1923	1924	1925	Av.
Manchuria, Minn. No. 184	15	27	30	24	23	24
Velvet, Minn. No. 447	14	29	30	21	21	23
Glabron, Minn. No. 445	14	28	23	24	22	22

*30 = Completely resistant.

3 = High susceptibility. The smooth-awned parent averaged 15 for 1921 to 1923, inclusive, and Manchuria, Minn. No. 184, and Luth, Minn. Nos. 24 and 25, respectively.

TABLE 2.—*Average yields in bushels per acre in rod-row trials, 1921–25, inclusive.*

Variety	University Farm
Manchuria, Minn. No. 184	48.6
Velvet, Minn. No. 447	52.8
Glabron, Minn. No. 445	53.0

TABLE 3.—*Annual and average yields in bushels per acre of barley varieties at University Farm and branch stations in Minnesota, 1922–27.*

Location of station	1922	1923	1924	1925	1926	1927	Average
	Velvet, Minn. No. 447						
Univ. Farm, St. Paul	67.2	28.2	25.4	46.3	48.5	43.4	43.2
Waseca	65.0	50.9	68.5	60.6	56.1	39.8	56.8
Morris	30.3	39.3	37.4	42.4	25.5	45.6	36.7
Crookston	53.0	37.8	31.3	32.2	45.4	32.8	38.8
	Manchuria, Minn. No. 184						
Univ. Farm, St. Paul	48.3	35.4	25.4	46.2	43.2	47.5	41.0
Waseca	70.4	49.5	70.3	58.2	55.1	41.3	57.5
Morris	31.0	37.5	40.8	43.1	24.1	43.6	36.7
Crookston	53.6	34.8	44.1	30.3	38.6	26.0	37.9
	Glabron, Minn. No. 445						
Univ. Farm, St. Paul	67.2	33.8	40.4	52.5	59.5	45.4	49.8
Waseca	70.4	47.0	74.2	58.3	46.8	39.4	56.0
Morris	29.0	36.8	46.6	42.0	30.3	50.0	39.1
Crookston	58.2	34.1	45.8	32.3	41.2	27.6	39.9

TABLE 4.—*Percentage and degree (where 90 is flat) of lodging in seasons when lodging was severe at University Farm and branch stations in Minnesota, for the years indicated.*

Variety	Rod rows St. Paul 1921	Rod rows St. Paul 1923	Rod rows St. Paul 1925	1/40-acre plats St. Paul 1925	St. Paul 1926	Waseca 1924	Waseca 1925	Waseca 1927	Crookston 1927	Morris 1924
	Precentage of Lodging									
Manchuria, Minn. No. 184	100	17	100	38	60	97	28	100	88	57
Velvet, Minn. No. 447	100	24	100	57	60	15	42	0	28	17
Glabron, Minn. No. 445	100	0	23	7	15	0	10	0	0	15

TABLE 4.—*Cont.*

Variety	Rod rows					1/40-acre plats				
		St. Paul		St. Paul		Waseca		Crookston		Morris
	1921	1923	1925	1925	1926	1924	1925	1927	1927	1924
	Degree of Lodging									
Manchuria, Minn. No. 184	26	5	74	62	25	67	55	40	15	50
Velvet, Minn. No. 447	31	13	89	56	47	40	28	0	5	35
Glabron, Minn. No. 445	14	0	50	43	10	0	30	0	0	25

NOTE

MAGNESIUM AND CALCIUM CHLORATE AS SUBSTITUTES FOR SODIUM CHLORATE FOR KILLING FIELD BINDWEED

The Kansas Agricultural Experiment Station has been using sodium chlorate to kill field bindweed with considerable success, as reported in the *Journal of Agricultural Research* for October 15, 1927, and in Kan. Agr. Exp. Sta. Cir. No. 136, published in 1928. The first experiments with this chemical were begun in 1925.

It has been observed in experiments in progress at this station that magnesium chlorate and calcium chlorate may be used as substitutes for sodium chlorate in the control of field bindweed. Experiments conducted during the past year suggest that these chemicals are as effective as sodium chlorate and that they have certain advantages.

In the first place, they do not form a combustible mixture with organic material since magnesium chlorate normally carries six and calcium chlorate two molecules of water of crystallization, while sodium chlorate forms an anhydrous salt. Hence, with the former there is no fire hazard as with sodium chlorate. Another important advantage is that they are very hygroscopic and remain moist on the leaves a much longer time when applied in solution than does sodium chlorate. In a dry atmosphere the latter forms crystals in a short time and in that condition is less destructive to plant tissue.

While experimental evidence is meager, these facts suggest that magnesium and calcium chlorate will be effective within a wider range of weather conditions than sodium chlorate, and that they may be particularly adapted to semi-arid conditions where sodium chlorate, because of its tendency to crystallize from solution, is not entirely satisfactory.

Magnesium and calcium chlorate have been chemical curiosities and until recently have not been on the market even in sufficient quantities for experimental purposes. They are now available in commercial quantities. Magnesium chlorate is being manufactured on a commercial scale by the Dow Chemical Company, Midland, Michigan, and calcium chlorate may be obtained in dry or liquid form from the Chipman Chemical Engineering Company, Bound Brook, New Jersey, and is sold under the trade name of Atlas Non-poisonous Weed Killer.—W. L. LATSHAW AND J. W. ZAHNLEY, *Kansas Agricultural Experiment Station, Manhattan, Kansas.*

MEMORIAL TRIBUTE TO A. J. OGAARD

Agriculture of America lost an outstanding worker in the death of A. J. Ogaard at Salt Lake City on August 27, 1928.

He was born in Minnesota and received his undergraduate instruction at the University of Minnesota and the North Dakota Agricultural College, graduating from the North Dakota Agricultural College in 1913. From 1913 to 1918 he was identified with the Office of Dry Land Agriculture, United States Department of Agriculture, with headquarters in North Dakota. In May 1918, he was appointed county agricultural agent of Chouteau County, Montana. In 1921, he was called to a larger field of service when he was appointed extension agronomist of the Montana extension service, which position he held until April 1, 1928 when he resigned to accept the position of executive secretary of the Farm Seed Association of North America.

Throughout his life Mr. Ogaard was a tireless worker for the advancement of agriculture. In fact, those who knew him best believe that his span of life would have been lengthened had he been more careful to conserve his energy. However, it was characteristic of Mr. Ogaard to give unsparing of himself to every task which he undertook.

During his period of service as extension agronomist in Montana he did all within his power to make farm life more pleasant and more profitable. The humble tribute of a farmer in Chouteau County, "He did a lot for us fellows," speaks volumes in terms of personal service and the accomplishments by which the Montana public came to know him.

One of Mr. Ogaard's greatest contributions to agriculture was made through his interest in the development of practical plans of crop standardization and improvement and distribution of farm seed. Through his efforts the Montana Seed Growers Association was brought to a high state of efficiency. His work in connection with the International Crop Improvement Association and the recently organized Seed Council of North America has done much to bring about better relations among the various agencies connected with the seed industry of this country.

Mr. Ogaard was a fearless, yet fair, frank, and sincere worker. He is no longer with us but his influence remains as an inspiration to a life of greater service and will continue as a potent force for the betterment of American agriculture.

CLYDE MCKEE
R. I. THROCKMORTEN

FELLOWS ELECT, 1928

CURTIS F. MARBUT

CURTIS F. MARBUT has directed the work of the Soil Survey Division of the Bureau of Chemistry and Soils of the United States Department of Agriculture since 1910. He was born and reared on a farm in the State of Missouri and was graduated from the University of Missouri (B.S.) in 1889.

His first scientific work was in geology. He served as assistant geologist, Missouri Geological Survey, 1890 to 1904, and after a year of graduate work at Harvard, was appointed Instructor in Geology in the University of Missouri. He was made Assistant Professor in 1897, and Professor in 1899, which position he retained until he resigned in 1910 to assume his present position with the United States Department of Agriculture. In 1916 he received his doctor's degree from his Alma Mater.

Doctor Marbut has achieved an international reputation in soil science, and he is generally recognized as one of the world's foremost authorities on soil classification and cartography. His interests and investigations have been world-wide. They have taken him not only to all parts of the United States, but to South America, Europe, Canada, and Cuba. Soilsinvestigations in many other parts of the world have been conducted under his direction.

At the recent centenary celebration of the Berlin Geographical Society Dr. Marbut was elected to corresponding membership in recognition of his work in the field of geography.

Doctor Marbut was President of the Association of American Geographers in 1924; Chairman of Section O of the American Association for the Advancement of Science in 1926; and Chairman of the Fifth Commission on Classification and Nomenclature, and the Mapping of Soils in the International Society of Soil Science since 1924.

He has been a member of the American Society of Agronomy since 1911, and has taken active part in most of the meetings of the Society.

ADRIAN J. PIETERS

ADRIAN J. PIETERS, Senior Agronomist, Acting in Charge of Forage Crops, spent his boyhood days in Michigan and received from the University of that state his B.S. and Ph.D. Dr. Pieters' first association with the United States Department of Agriculture was in 1895, when he was appointed as an assistant botanist. In 1900 he was made the Botanist in Charge of Seed and Plant Introduction, which position he filled with distinction until 1906. From 1906 to 1910, Dr. Pieters engaged in the growing of seed in California and spent the following year in special study at the University of Heidelburg, returning to serve his Alma Mater in 1912, where he remained until 1915.

In 1915 Dr. Pieters was again called to the Department of Agriculture to take charge of the clover work in the Office of Forage Crops and during the past two years has been the Agronomist Acting in Charge of the Forage Crop project. Dr. Pieters has made a notable contribution to science and as a result of his research has published extensively.

In addition to his work on clovers, the problem of maintaining soil fertility by green manuring early attracted his interest and became his special study, resulting in publication in the JOURNAL of the American Society of Agronomy and elsewhere on the subject. Pursuing his green manuring research further, Dr. Pieters published, in 1927, his comprehensive work—Green Manuring; Principles and Practice. In the same year, the Department of Agriculture, recognizing the importance of the green manuring problem, created a special committee to make an organized and intensive study of the subject, appointing Dr. Pieters its first Secretary.

GEORGE ROBERTS

GEORGE ROBERTS is Professor of Agronomy and Head of the Department of Agronomy in the College of Agriculture and in the Agricultural Experiment Station of the University of Kentucky. He is also Assistant Dean of the College of Agriculture. He is a native of Kentucky, growing up on a farm in that state. He graduated from the University of Kentucky with the degree of Bachelor of Pedagogy in 1899 and the degree of Master of Science in Chemistry in 1901. He became Assistant Chemist in the Kentucky Agricultural Experiment Station on his graduation and has been in the continuous service of his Alma Mater since, with the exception of the period 1906 to 1909 when he was Assistant Chemist in the California Agricultural Experiment Station. He became Head of the Department of Agronomy in 1909 shortly after its organization. He was Acting Dean of the College of Agriculture during the interim from the death of Joseph H. Kastle, the former Dean, until the appointment of Thomas P. Cooper, the present Dean. He served the American Society of Agronomy as treasurer for the period 1913 to 1917. In addition to the American Society of Agronomy, he is a member of Sigma Xi, Phi Beta Kappa, Alpha Zeta, the American Association for the Advancement of Science, the Association of Southern Agricultural Workers, the Kentucky Academy of Science, and the Research Club of the University of Kentucky.

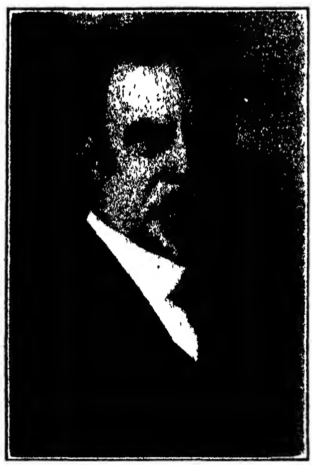
Throughout a long period of service, Professor Roberts has conscientiously, wisely, and self-effacingly served the University and State of Kentucky, always with a steadfast adherence to what he considered right, and with no thought of his own interests. His period of service extends through the time in which most of the growth of the University of Kentucky has taken place. He has always been keenly interested and active in many ways in its life and has contributed very largely to its development. He has worked incessantly and effectively in the classroom, through the agricultural press, in publications of the Kentucky Experiment Station, in frequent addresses at farmers' meetings and other agricultural meetings in his state for the development of the agriculture of Kentucky.

He was one of the pioneers in the country in emphasizing the importance of and in striving for the management of soils to conserve and increase their productiveness. He early started and has developed a fairly extensive and well-planned system of soil experiment fields in Kentucky. These are a potent factor in the better management of the soils of the state and their influence is wider than state lines. To his labors, far-sighted vision, and constructive purpose is mainly due the growth of agronomic work in the state to the place of wide confidence on the part of the people and of large service it now has.

Professor Roberts is a delightful man to know personally, and one under whom and with whom it is a pleasure to work.

OSWALD SCHREINER

Oswald Schreiner is in charge of Soil Fertility Investigations in the Bureau of Chemistry and Soils, United States Department of Agriculture. He was born ni Nassau, Germany, and came to the United States with his parents in 1883, settling in Baltimore, Maryland.



He was graduated at the Baltimore Polytechnic in 1892 and at the Maryland College of Pharmacy in 1894, receiving three gold medals for his proficiency in chemistry. He continued his studies in chemistry at the Johns Hopkins University and the University of Wisconsin, receiving from the latter the degree of B.S. in 1897, M.S. in 1899, and Ph.D. in 1902. While at the University of Wisconsin, he was instructor in physical chemistry.

In 1902 he was appointed expert in physical chemistry investigations, Bureau of Soils, U. S. Department of Agriculture, becoming chemist in 1903, soil chemist in 1904, and Chief of the Division of Soil Fertility Investigations in 1906. In 1915 he was transferred to the Bureau of Plant Industry as Biochemist in charge of Soil Fertility Investigations. On July 1, 1927, his division was transferred to the Bureau of Chemistry and Soils and in July, 1928, Dr. Schreiner was appointed Principal Biochemist in charge of Soil Fertility Investigations.

Dr. Schreiner has made a study of soil fertility and its maintenance, causes of unproductive soils, transformation of soil humus by biochemical factors, origin of organic constituents in soils, and means for improvement of unproductive soils and is the author of many scientific papers on these subjects. The field work of

the division under his charge, involving soil fertility and fertilizer investigations, has increased a great deal since 1913 with the establishment of experimental work in about 25 states.

Dr. Schreiner has won a national reputation by his many lectures at agricultural colleges and before farmers' institutes and clubs and scientific societies. The Evert prize was awarded to him in 1900 for chemical investigations on sesquiterpene hydrocarbons and derivatives and the American Pharmaceutical Association prize in 1900 for chemical investigations on sesquiterpenes. He received the Longstreth medal of merit for "important researches in agricultural chemistry" from the Franklin Institute in 1912.

His laboratory researches upon the fundamental principles of soil fertility, especially that relating to the chemistry and biochemistry of soil organic matter or humus and its function in promoting or hindering plant development, have won for Dr. Schreiner and his associates a leadership among soil scientists and agronomic investigators at home and abroad. To the laboratory under his direction belongs the credit for the chemical discovery, physical separation, and plant physiological study of over 50 new soil organic compounds which have materially altered the fundamental conception of scientists regarding soil humus and its formation and transformation by plants and micro-organisms, and its effects and functions in crop production. He is the inventor of the Schreiner colorimeter, which, on account of its great applicability to various lines of research, is widely used in chemical laboratories in this country and abroad.

Dr. Schreiner is a member of the American Chemical Society, the American Association of Biological Chemists, the American Society of Agronomy, Washington Academy of Science, International Society of Soil Science, the Botanical Society of America, the American Potato Association, the Phi Beta Kappa Society, the Cosmos Club, and a Fellow of the American Association for theAdvancement of Science. He has been President of the Association of Official Agricultural Chemists, serving in this capacity at its last meeting during October, 1928, in Washington, D. C.

ALFRED T. WIANCKO

ALFRED T. WIANCKO is Head of the Department of Agronomy at Purdue University. He was born and educated in Canada, being a graduate of the Ontario Agricultural College and the University of Toronto. After graduation he was elected Assistant in Chemistry at the Ontario Agricultural College. The following year he went to Minnesota as manager of a large farm. Two years later he returned to the Ontario Agricultural College as Assistant Librarian and Instructor in German. In 1901 he came to the United States as Experimentalist for the Standard Cattle Company at Ames, Nebraska, giving special attention to problems in sugar beet production. In the fall of that year he was elected Assistant Agriculturist and Instructor in Agriculture in the University of Nebraska. In 1903 he was called to Purdue University to take charge of the Agronomic work in that institution.

Professor Wiancko has made valuable contributions in crop improvement, directing the development and standardization of some of the leading varieties of corn for which Indiana has become famous. Under his direction, also, were developed the Michikof and Purkof varieties of wheat and the Dunfield soybean. In soil fertility investigations, Professor Wiancko has given special attention to field experiments and has established a comprehensive series of experiment fields throughout Indiana which are yielding valuable results, the experiments with different carriers of phosphorus and with different forms of lime being out standing. He is also the author of a large number of valuable soil fertility and crop improvement publications. He has been a leader in the campaign for high analysis fertilizers and is the author of the first simplified set of fertilizer recommendations for different crops under different soil conditions based on a detailed knowledge of the soils of the State.

Professor Wiancko is a charter member of the American Society of Agronomy and has served on several important committees. He was a member of the Committee on Standardization of Field Experiments for eight years, serving as chairman for six years during which time he gave much study to this subject and drew up the standards adopted by the Society in 1923. He was also active in organizing the American Soil Survey Association and was its third president.

AGRONOMIC AFFAIRS

PROGRAM OF JOINT MEETING OF SECTION O, A.A.A.S., AND NEW ENGLAND SECTION OF SOCIETY

Room 327, Macy Hall, Teachers' College, New York City,
9:00 A.M., December 28, 1928

SYMPOSIUM ON "PASTURE MANAGEMENT RESEARCH"

1. Comparative returns in feed units from crop rotations and pastures.
J. W. WHITE, State College, Pa.
Discussion by R. M. Salter, Wooster, Ohio
2. Income from land in crops and pasture. E. G. MISNER, Ithaca, N. Y.
Discussion by R. H. Barrett, Amherst, Mass.
3. Practices and conditions determining the most productive permanent pastures of New Jersey. H. B. SPRAGUE, New Brunswick, N. J.
Discussion by J. B. R. Dickey, State College, Pa.
4. Ecological factors determining pasture flora of the northeastern states. H. P. COOPER, J. K. WILSON, and J. H. BARRON, Ithaca, N. Y.
5. The Hohenheim system of pasture management.
K. PETER, New York City
Discussion by J. S. Owen, Storrs, Conn.
6. Pasture investigations in the southeastern states.
H. N. VINALL, Washington, D. C.
7. Range research of the United States
W. R. CHAPLINE, Washington, D. C.
Discussion by L. W. Kephart, Washington, D. C.
8. Analysis of seeding mixtures and resulting stands in irrigated pastures of northern Colorado. H. C. HANSON, Fort Collins, Col.
9. Eradication of weeds and brush in pastures.
A. E. ALDOUS, Manhattan, Kans.
Discussion by H. C. Hanson, Fort Collins, Col.
10. A critical comparison of methods of conducting pasture experiments. G. L. SCHUSTER, Newark, Del.
Discussion by C. F. NOLL, State College, Pa.
11. The effect of fertilizer treatments on the quantity and quality of pasture vegetation:
A. Mineral treatments. B. A. BROWN, Storrs, Conn.
B. Nitrogen treatments. HENRY DORSEY, Storrs, Conn.
Discussion by R. A. Payne, Northampton, Mass.
12. Certain factors affecting the chemical composition and nutritive value of pasture grasses.
J. G. ARCHIBALD and P. R. NELSON, Amherst, Mass.
13. The rôle of pasture in the mineral nutrition of animals.
L. A. MAYNARD, Ithaca, N. Y.
Discussion of papers 12 and 13 by H. B. Ellenberger, Burlington, Vt.

BUSINESS MEETING OF NEW ENGLAND SECTION OF SOCIETY

JOINT BANQUET FOR SECTION O AND NEW ENGLAND SECTION OF SOCIETY

6:30 P.M.

Toastmaster: P. E. Brown, Ames, Iowa

Increased efficiency of American agriculture.
L. E. Call, Manhattan, Kans., retiring Vice-President of Section O

Green pastures.
F. J. Sievers, Amherst, Mass.

English pastures as I have seen them.
S. B. Haskell, New York City

Film on pasture work.
J. B. Abbott, Bellows Falls, Vt.

MINUTES OF THE TWENTY-FIRST ANNUAL MEETING

The meeting was called to order by President A. G. McCall, at 9:30 a. m., on Thursday, November 22, at the Willard Hotel, Washington, D. C. More than 260 members and visitors registered and at least 300 were present at the various sessions. There were members present from Russia, Germany, Honduras, Canada, Alaska, and South Africa, and representatives from 40 states and the District of Columbia.

The following special committees were appointed: *Nominating;* W. P. Kelley, Calif., Chairman; M. A. McCall, Washington, D. C.; and George Roberts, Kentucky. *Resolutions*, R. W. Thatcher, Mass., Chairman; J. D. Luckett, New York. *Auditing*, T. K. Wolfe, Va., Chairman; M. F. Morgan, Conn. A special committee, consisting of J. G. Lipman, New Jersey, and C. R. Ball, Washington, D. C., was named to confer with a similar committee from the American Soil Survey Association in regard to the International Society of Soil Science.

The program as arranged was presented, two sections meeting in the afternoon. The program is given on page 1358.

The annual dinner was held at 6:30 p. m., in the Willard Hotel, 147 attending. President A. G. McCall delivered an address on "A National Program of Soil Research" which appears on pages 1241 to 1250 of this issue of the Journal. The business session was then held.

FELLOWS ELECTED

Vice-President W. W. Burr presented the names of the Fellows Elect and read a short biographical sketch of each. (See pages 1331 to 1335 of this number of the Journal.) They were Dr. C. F. Marbut, Dr. Oswald Schreiner, Dr. A. J. Pieters, Prof. A. T. Wiancko, and Prof. George Roberts. Diplomas were then presented. Prof. Wiancko was unable to be present at the meeting.

Dr. R. W. Thatcher spoke of the sudden death of A. J. Ogaard and O. S. Fisher presented a statement regarding Prof. Ogaard which was received by a rising vote of respect and the secretary was instructed to send a copy to the family. The statement appears on page 1330 of this number of the Journal.

OFFICERS REPORTS

J. D. Luckett, Editor, presented his report, which upon motion was accepted

REPORT OF THE EDITOR

As a preface to this my first report as the Editor of your JOURNAL it is altogether fitting that I should acknowledge to my predecessor, Dr. R. W. Thatcher, receipt of a publication in such vigorous health and so well established in the way in which it should go that my efforts have been directed chiefly at attempting to maintain the high scientific and editorial standards set up by him. I trust that the period of adjustment of the ample folds of his mantle to my frail shoulders has not too greatly tried your patience.

With the close of 1928, the JOURNAL will have completed its twentieth volume. In comparison with preceding volumes, Volume 20 promises to establish several new records. In point of size it will exceed any previous volume by nearly 200 pages. It will contain 19 more contributions than the preceding volume. It will probably be more representative of agronomic activities in the United States than any previous volume, as shown by the geographical distribution of the published papers. It will show a noticeable gain over the preceding year in the proportion of soil papers to crop papers. It will show an appreciable increase in advertising income. And unfortunately, but true nevertheless, it will cost slightly more per page than did Volume 19, when costs are computed on a comparable basis.

A comparison of costs for the past six volumes is presented herewith:

Vol. No.	No. of pages	Total cost	Advertising Income	Reprints sold	Net cost	Cost per page
15	538	$3,221.56	$ 697.60	$ 94.62	$2,229.34	$4.13
16	824	4,392.79	783.97	500.40	3,106.40	3.77
17	846	4,538.19	734.65	462.03	3,341.65	3.95
18	1170	6,357.05	1,125.41	794.00	4,437.64	3.79
19	1162	6,436.16	1,254.94	825.39	4,355.83	3.75
20*	1124	6,141.24	1,135.97	674.93	4,330.34	3.85

*First ten issues.

When the December number comes from the press there will have appeared in the current volume of the JOURNAL 102 contributed articles, 17 symposia papers, 12 notes, and 12 book reviews. On November 1 there were in the Editor's hands 8 contributed articles and 2 book reviews which had been accepted for publication. Eight contributions of one sort or another have been returned as unsuited to the JOURNAL, making a total of 161 manuscripts passing through the Editor's hands during the first ten months of the year.

With the completion of Volume 20, all contributions accepted prior to October 1 will have been published. However, with a sufficient number of papers already on hand to make a normal issue of the JOURNAL for January, 1929, and with the large number of papers from this meeting that will be almost immediately available for publication, the Society faces for the first time in recent years a threatened congestion in its publication schedule. The Editor deems it inexpedient to expand the JOURNAL much, if at all, beyond the limits of the present volume, unless increased revenues from advertising or subscriptions appear to justify the increased cost.

In our estimation the scientific quality of most of the papers offered for publication in the JOURNAL is of a high standard. We do feel, however, that many of the papers submitted to us are too long. More time and effort are expended in the process of elimination than in any other editorial function that we perform. We do not regard it as wise or desirable to fix an arbitrary limit on the number of

manuscript pages that will be accepted for publication, but we do believe that if the JOURNAL is to continue to serve the Society in the future as it has in the past few years by speedy publication of agronomic contributions more attention must be given by authors to condensation of their material.

Classifying the contributed articles, symposia papers, and notes published in Volume 20 by point of origin, we find that contributions have been received from 32 states, the District of Columbia, and Canada. We believe that this is a most satisfactory record and an admirable index to the worth of the JOURNAL as a medium for an exchange of agronomic information.

Below is a list of the states represented and the number of papers from each.

Alabama	6	Montana	1
Arkansas	6	Nebraska	3
California	4	New Jersey	3
Canada	1	New York	7
Colorado	1	North Dakota	3
Connecticut	1	Ohio	9
Delaware	1	Oklahoma	6
District of Columbia	24	Oregon	3
Florida	2	Pennsylvania	1
Illinois	6	South Carolina	1
Indiana	2	South Dakota	1
Iowa	1	Tennessee	2
Kansas	1	Texas	7
Massachusetts	3	Utah	4
Michigan	6	Washington	1
Minnesota	9	West Virginia	5
Missouri	2	Wisconsin	7

We have watched with interest during the past year an apparent trend toward a greater proportion of soils papers offered for publication in the JOURNAL as compared with papers dealing with crop subjects. Comparing 1927 with 1928 in this respect, we find that in 1927 approximately 67% of the papers and notes published in the JOURNAL had to do with crops as compared with 58% in 1928. Similarly, in 1927, soils papers represented 24% of the whole, while in 1928, 32% of the papers will deal with soil subjects. The remaining papers in each year are classified as miscellaneous.

The 1928 income from advertising in the JOURNAL will show a gain of nearly $100 over that for 1927, or about $1,350 in all. It is reasonable to expect that most of this advertising will remain with the JOURNAL during 1929, in fact much of it is already under contract. We hope also that added revenues may be forthcoming from this source. Advertising in a Journal such as ours takes the form largely of good will advertising and, in most cases, cannot be solicited on the same basis as ordinary sales promotion advertising. Good will implies reciprocity on our part, and we earnestly commend to your consideration the well-worn phrase "When writing to our advertisers, please mention this JOURNAL."

At the suggestion of a former Editor of the JOURNAL and a member of the Editorial Advisory Committee the advertising pages of the JOURNAL have been opened at a nominal fee to agronomists seeking positions and institutions seeking agronomists, under the caption of "The Agronomist's Service Bureau." The response to this offer of our pages as a common meeting ground for employer and employee has met with but faint response thus far, but the opportunity stands open when occasion may prompt you to act.

At the last annual meeting of the Society the Executive Committee authorized the Editor to prepare a cumulative index of the first twenty volumes of the

JOURNAL and to ascertain the cost of publication of such an index. Work has progressed sufficiently on this index to make it possible to state at this time that a subject and author index of the JOURNAL from the first volume of proceedings through Volume 20, in paper covers, may be had for fifty cents per copy. A prospectus of the index and an order blank will be forwarded to each member of the Society and subscriber to the JOURNAL early in the year.

A request addressed to each department of agronomy in the several agricultural colleges and experiment stations for some one to serve as "correspondent" for the JOURNAL has met with a most gratifying response, and the Editor welcomes this opportunity to express his gratitude to those who have made possible the "News Items" appearing in the JOURNAL from time to time.

The plan adopted by the Society at its last meeting of creating an Editorial Advisory Committee to assist the Editor in determining matters of policy and in the selection of papers for publication in the JOURNAL has proved most satisfactory. This committee, all of whom have served the Society in an editorial capacity, has rendered invaluable aid to the Editor and has his profound thanks, and we hope that it will be retained for the coming year.

Finally, we wish to acknowledge the help and encouragement that have marked our dealings throughout the year with our genial Secretary, Dr. Brown. Our troubles and short comings must have tried his patience, but of that he gave no hint in his ready response to our every need.

P. E. Brown, Treasurer, read his annual report, which was received and referred to the Auditing Committee. Professor T. K. Wolfe reported that the Auditing Committee had examined the books and vouchers of the Treasurer and found them correct. The report was accepted.

REPORT OF THE TREASURER

I beg to submit herewith the report of the Treasurer for the year November 1, 1927, to November 1, 1928.

Balance, last report, general fund	$1,418.41
Balance, last report, Lime Assoc. fund	147.20
Total balance, last report	$1,565.61

RECEIPTS, 1928

Dues, 1928	$3,433.80	
Dues, 1928, new	529.50	
Dues, 1927	75.00	
Dues, 1929	10.00	
Subscriptions, 1928	996.37	
Subscriptions, 1928, new	369.63	
Subscriptions, 1927	36.75	
Subscriptions, 1929	23.00	
Advertising income	1,290.00	
Reprints sold	826.41	
Journals sold	429.77	
Total receipts	$8,020.23	$8,020.23
Total income, 1928		$9,585.84

DISBURSEMENTS, 1928

Printing the JOURNAL—reprints, etc. (12 issues Oct. 1927–Sept. 1928)	$7,266.46	
Salary Business Mgr. (12 months.)	747.50	
Printing (programs, stationery, etc.)	171.83	
Postage (Secretary and Business Mgr.)	191.85	
Freight, express, and drayage	31.09	
Refunds on checks, dues returned, etc	22.90	
Miscellaneous (supplies, expenses of annual meeting, mailing JOURNAL, reprints Ball article, etc.)	248.66	
Total disbursements	$8,680.29	$8,680.29
Balance on hand		$905.55
Balance, Lime Assoc. fund	147.20	
Balance, general fund	758.35	
Total balance	$905.55	
Total income	$9,585.84	
Total disbursements	8,680.29	
Balance	$ 905.55	

Respectfully submitted,

P. E. BROWN, *Treasurer.*

The report of the Secretary was then read and upon motion was accepted.

REPORT OF THE SECRETARY

In accordance with the requirements of our laws, customs, traditions, or "what have you," we must all suffer through what is called the "report of the Secretary;" I, who must make the report and you, who must listen. But the agony will all be over in two or three hours, so be patient. Now you may drape yourselves over the chairs as comfortably as possible and prepare for a short nap and if you will sleep quietly and not prevent our being heard by such as may remain awake, we will not object nor disturb you.

With this "high brow" introduction out of our system and with a full understanding between us, here comes the report!

Membership:—Our membership has increased from 767, as reported last year, to 823. There were 109 new members added to the Society and 36 reinstated, giving a total increase of 145. Ten resignations, 2 deaths, and 77 suspensions for non-payment of dues made a total decrease of 89, thus leaving a net increase of 56. We seem to be making a healthy growth.

The large number of new members is evidence of the activity of the representatives of the Society in the different states and of the enthusiastic support of some of our good friends. We are indebted to all these loyal "boosters" for the Society and I recommend that the Society extend them a vote of thanks and urge them to keep up the good work and "be not weary in well-doing." The list of representatives was the same as the previous year.

Similar tactics to those followed during the past few years have been employed in the attempt to induce, inveigle or otherwise cajole our members to stay with us. The great majority are so well-trained now that they need only one notice and "my gosh, how the money rolls in." But after the second and third notices have elicited no response, we have recourse to a new series of "soul-stirring," "heart-rending" appeals, with a gradual crescendo in the moving motif and a few more racking sobs in every line. Few can resist these wails or else they fear the

prospect of indefinite continuance. At any rate the method seems to bring results. We had almost a 50 percent reinstatement this year. One member thought that he would like the whole series of letters but feared the effect on his nervous system, and well he might! Anyone who can resist many of these direct attacks has no nervous system—nothing but gristle and bone. In fact our private opinion is that those who stubbornly refuse to return to the fold of abundance of mental pabulum and a surfeit of stimulating incentives, to say nothing of inspiring contacts and enduring friendships (the Society is all this!) are more or less "boneheaded."

But to make a short story long, we make it just as difficult as possible for any member to get away from us. But if they do insist upon serving "diplomatic relations," we console ourselves with that most philosophical thought that they are "too damned dumb to understand."

Our membership lists are kept alphabetically on cards and on a loose-leaf members register, by states and by years of admission into the Society. The membership by states and countries is as follows:—

					8
Alabama	12	Africa	10	Oregon	4
Arizona	6	Alaska	3	Pennsylvania	12
Arkansas	7	Argentina	8	Rhode Island	1
California	20	Australia	5	South Carolina	18
Colorado	5	Bolivia	1	South Dakota	1
Connecticut	11	Brazil	1	Columbia	2
Delaware	3	Brit. W. Indies	1	Cuba	1
Dist. of Col	62	Canada	32	Denmark	3
Florida	14	China	4	Egypt	5
Georgia	20	Maryland	10	England	4
Idaho	6	Massachusetts	12	Germany	1
Illinois	39	Michigan	19	Haiti	1
Indiana	20	Minnesota	19	Hawaii	13
Iowa	33	Mississippi	6	Honduras	3
Kansas	25	Missouri	16	India	1
Kentucky	6	Montana	12	Italy	7
Louisiana	8	Nebraska	18	Japan	1
Maine	5	Nevada	1	Jugoslavia	1
Tennessee	9	New Hampshire	2	Mesopotamia	2
Texas	34	New Jersey	8	Mexico	2
Utah	8	New Mexico	4	Peru	3
Vermont	2	New York	38	Philippine Islands	1
Virginia	16	North Carolina	11	Poland	4
Washington	10	North Dakota	18	Russia (U. S. S. R.)	2
West Virginia	9	Ohio	31	Sweden	1
Wisconsin	26	Oklahoma	11	Turkey	
Wyoming	4				

The membership by years of admission is as follows:—

1908 (Charter)	36	1915	30	1922	38
1908	10	1916	52	1923	24
1909	5	1917	24	1924	42
1910	16	1918	17	1925	87
1911	23	1919	15	1926	84
1912	18	1920	27	1927	92
1913	21	1921	41	1928	107
1914	14				

Very few losses occur among the old-timers on this list, the changes are found mainly among the recent additions.

The total membership by years is as follows:—

1908	121	1915	471	1922	643*
1909	129	1916	586	1923	561
1910	176	1917	652	1924	577
1911	236	1918	509	1925	646
1912	295	1919	473	1926	700
1913	349	1920	436	1927	767
1914	397	1921	592	1928	823

*In 1922 the dues were increased to five dollars.

We shall probably reach a maximum membership some of these days but no one knows just what the "saturation" point for Agronomists is—this does not refer to the political "wet" issue nor to the saturation point for any individual Agronomists. If any research is to be carried out along this line, Washington should be a good place to do it, according to all accounts (we have no personal information along this line).

I would bespeak the support of each and every one of the members of the Society in securing new members and in keeping our old members from "back sliding."

Subscriptions.—The number of subscriptions has increased from 324 to 387, a net increase of 63. There were 85 new subscriptions received during the year and 22 were dropped. We still have requests for the JOURNAL on exchange but always insist on the subscription price and it rarely fails to appear. The increased demand for the JOURNAL among libraries is a definite evidence of its standing and value.

Journals sold.—The demand for complete sets of the JOURNAL continues, but Volumes 1, 3, 4, and 8 and one number of Volume 5 are out of print. We have supplied many orders for all other issues and for individual copies. The unfortunate part of this situation is that we have stacks of copies of some issues and are very short on others and there seems no way to even up.

Finances.—The finances of the Society continue sound. We have paid for 12 issues of the JOURNAL and all other expenses and still have a balance on hand. The JOURNAL gets "better and better, every day in every way" and is worth more. The increased income from advertising is a great help, and Mr. Luckett is entitled to much credit for his work in this connection.

Committees.—All standing committees were appointed by President McCall and the Special Committees on Corn Borer Investigations, Fertilizer Distributing Machinery, and the Chilean Nitrate of Soda Research Award were reappointed. A new Special Committee on Fertilizers was appointed and a new Sub-committee on Soybean Registration was created.

Meetings.—A joint meeting with Section O of the American Association for the Advancement of Science was held at Nashville with a very interesting symposium on the corn borer situation and a joint dinner featured by the address of the retiring chairman of Section O, Dr. C. F. Marbut.

The New England Section met on December 2 and 3 at Boston and had a fine meeting. On January 25 and 26 they met for a Joint Conference with the New England Fertilizer Association. Plans have been made for a joint program with Section O of the Association on December 28 in New York City. A symposium on pasture management research will be presented and a joint dinner will be arranged at which Chairman L. E. Call of Section O will deliver his retiring address.

The Southern Section was to have met in August in Mississippi, but we have had no report on the meeting.

The Western Section met at Davis and Berkeley California on June 19 to 21 and had an excellent program.

The Corn Belt Section met at Columbus and Wooster, Ohio, on June 21 to 23 and everyone attending reported a most enjoyable and profitable time. Programs for this meeting were distributed from our office. The next meeting of this Section will be held in Kansas.

The Mexican Agrological Society was organized on July 12 at Meoqui, Mexico, with Prof. W. E. Packard as President. We had some correspondence in regard to this Society and it is apparently modeled after the Agronomy Society. It may be desirable to arrange affiliation with this organization.

Miscellaneous.—Our correspondence for the year has been much more voluminous than we expected, but then we expected it would be. Much has been interesting, some boring and considerable quite routine in nature. If time permitted I should like to take you on a trip thru my files. It would prove interesting.

Speaking of trips, one could very easily take a vacation, theoretically, by a study of the vast mass of pamphlets, circulars, pictures, etc., that come from the many cities that are languishing for us to meet amid the unparalleled conditions which they can provide.

How they long for our distinguished presence! How they soar to heights of extravagance in their perfervid statements! How the floods of enthusiasm swirl and eddy around us, from the steady downpour of superlative descriptions! It is enough to engulf one. Why, I have almost felt regretful at times that we could not change our plan and meet in some of these wonderful cities!

And the hotels—how could anyone wish for anything more desirable than to enjoy the luxurious comforts, the unsurpassed attractions of the many hostelries of our Capital city and of other towns all over the country. I have reached the conclusion that the hotel business is so good that they have plenty of money for advertising or else it is so poor that they are exerting themselves to the utmost to outdo the other fellow in extensive and fancy publicity. I have one entire file devoted to hotel propaganda.

Then of course, the usual mass of advertising for badges, souvenirs, printing, stenographic reports of our meetings (which might not be such a bad idea at that), bus rides, sight seeing tours, flowers, entertainment of a wide variety, lectures and so on ad infinitum. If we didn't have to worry about base exchange, be buried under organic matter, smothered with tobacco, or "carried away" by erosion, we might have a very entertaining program of tours, dinners, dances and other amusements and be delightfully frivolous. That's probably the kind of a meeting your wives think you are attending anyhow, even if you did try to convince them otherwise!

But we try to be quite dignified and to plan to entertain ourselves and its terribly hard to convince these professional entertainers than a bunch of dry-as-dust scientists or agronomists (whatever they are) can take care of themselves. Their opinion of us would probably prove interesting. But we should worry about that as long as "everybody's happy." If any of you have any suggestions, however, regarding the meetings, or other Society matters, don't hesitate to let us have them. We are always glad to hear from you.

I deeply appreciate the opportunity for contact with all Agronomists and the many courtesies shown me. I also wish to thank President McCall and Editor Luckett for their invaluable aid and encouragement in conducting the work of the office.

Respectfully submitted,

P. E. Brown, *Secretary.*

COMMITTEE REPORTS

Dean L. E. Call reported for the Special Committee on Corn Borer Investigations appointed by the American Society of Agronomy, the American Association of Economic Entomologists, and the American Society of Agricultural Engineers, and upon motion the report was accepted and the committee continued.

THE EUROPEAN CORN BORER

The European corn borer, which was first discovered in New England in the summer of 1917, has continued its natural spread until at the present time (September, 1928) the insect occurs throughout more than 230,000 square miles of territory in North America including the whole or parts of the New England states; and New York, Pennsylvania, West Virginia, Ohio, Michigan and Indiana; and parts of the provinces of Ontario and Quebec, Canada. Vigorous measures have been taken to prevent long-distance spread by artificial means. This effort has been successful. The only known spread of any importance in the United States, therefore, has been by the natural flight of the corn-borer moths or by water-drift of infested material. This spread has been at an average rate of from 20 to 30 miles per year. From any information now available there appears to be no practicable means of preventing this natural spread.

The results of the extensive studies of the borer in this country and in Central Europe furnish convincing evidence that the insect is of tremendous potentiality and ranks as one of the most alarming crop pests ever introduced. The situation, presenting, as it does, the possibility of a national calamity, calls for the continued cooperation of the farmer, the scientist, the educator, and all state and federal administrative officials.

The intensity of infestation by the corn borer in the western area has increased steadily since its discovery there in 1920. Before clean-up practices were applied in Kent and Essex counties, Ontario, severe commercial damage was suffered, and this resulted in a large reduction of corn acreage. Since clean-up practices have been applied in that district there has been a decrease in the intensity of infestation and an increase in acreage. This is a hopeful indication of the effectiveness of control measures and the possibility of continued corn production under conditions thought to be most favorable to the borer.

The cooperating committee of entomologists, agronomists, agricultural engineers, and agricultural economists wishes to indorse most heartily all efforts to control the corn borer, and to commend all persons engaged in the research, regulatory, and educational activities.

The committee recognizes the necessity for the fullest development of the research, educational, and quarantine programs of the State and Federal Governments and earnestly recommends the appropriation of the funds necessary to maintain and expand these activities. However, the committee does not favor a large federal appropriation for a compulsory clean-up campaign for the following reasons: (1) The break in the continuity of the clean-up program in 1928 due to the failure of the appropriation for this purpose; (2) the impossibility of securing an appropriation in time for an effective clean-up to protect the crop of 1929; and (3) the impractibility of enforcing effective clean-up measures under present state laws

After careful and complete investigation of the corn-borer regulatory, research, and educational activities, the committee suggests and recommends:

1. That the State and Provincial Agricultural Experiment Stations, the State Departments of Agriculture, and all other agencies interested in the welfare of American agriculture, give their support and encouragement to the Federal Governments of the United States and Canada in their policies on quarantine activities. Scouting should be continued in the areas contiguous to known infested areas and extended to the large corn-producing states where areas seem particularly exposed to infestation. Ample Federal funds should be available for a thorough clean-up of isolated infestations.

2. That major efforts in corn borer research, control, and educational activities be directed toward making possible the maintenance of our present corn acreage, in view of the economic importance of corn and the present advantages which this crop holds over any alternative crop as a revenue producer in the corn belt, and the certainty that farm incomes will be greatly reduced unless this is accomplished.

3. That the corn breeding program to produce strains that may be resistant or tolerant to the corn borer, or which may escape attack, should be continued.

4. That soil and cultural practices may avoid reduction in yield and quality of corn by the corn borer, such as time, rate, and method of planting, soil fertility treatments, and retardation studies, should be investigated further.

5. That studies should be continued on the physiology and morphology of the corn borer and its hosts, especially the corn plant, in relation to infestation, establishment, and damage and to the yield of corn.

6. That there be continued on many fields distributed over the area of heavy infestation, the study of the relation of corn borer infestation to time of planting, variety, soil type, height at the peak of moth flight, earliness of maturity and yield of corn.

7. That the study of the ecology of the corn plant be extended to the entire Corn Belt and that similar studies of the corn borer be extended as the spread of the insect permits.

8. That experiments on the long-time effect of various clean-up practices on soil productivity be continued.

9. That attention be given to studies of the possible substitution of other profitable crops for part of the corn acreage in the rotation in those sections where the corn borer promises to become a destructive pest. Such studies should include specifically the present and probable future market outlook for these substitute crops.

10. That studies should be made on reduction in yield or increased cost of crops other than corn, through changed methods as a result of the advent of the corn borer.

11. That efforts to determine the reduction in yield and quality of corn resulting from different densities of borer population should be continued and enlarged to include determinations of such damage at different degrees of soil productivity. Such information is essential to reliable recommendations as to varieties, cultural practices, and possible substitute crops for corn, as well as determining the clean-up practices that will be profitable.

12. That detailed cost-account work should be done, both within and outside of the infested areas, for the purpose of determining the costs of different farm operations, to serve as a basis for recommending changes in practices if they should become necessary.

13. That the important projects now under way to introduce and establish parasites of the corn borer from foreign countries, be continued and enlarged.

It also is recommended that all such initial introductions of parasites, predators, entomophthorous fungi and bacterial diseases from foreign countries be entirely under the direction and supervision of the United States Department of Agriculture or the Department of Agriculture for Canada.

14. That continued studies should be made of the habits, life history, and environmental influences affecting the spread of the corn borer and intensity of infestations, also upon the limitations of corn as to its seasonal, varietal and cultural practices. Such information is essential to combating the corn borer and will assist the entomologists, agronomists, and engineers in the development of controls.

15. That the experiments and demonstrations to determine the value of plowing under corn residues as a means of destroying the corn borer should be continued. These studies should include a determination of the comparative value of fall and spring plowing in different types of soil, with different widths and types of bottoms, on different dates, and at various depths.

16. That the experiments in the large screened areas should be continued to determine the relative degrees of infestation and damage to be expected, (a) where no effort at clean-up is made and (b) where the most practical clean-up methods are employed.

17. That investigations upon insecticides, repellents and attrahents be continued.

18. That in one-generation areas the study of weeds and plants other than corn be continued to determine what part these may play in the future as breeding hosts of the borer, especially in districts where, owing to the severity of the infestation, corn growing may be reduced temporarily.

19. That in view of the interdependence of machinery requirements and design, intensive development work should be continued. The experimental and research programs should be correlated with control methods and large-scale field procedure

20. That the control of the corn borer by mechanical means is of demonstrated importance and undoubtedly will continue to be so as long as the pest remains a menace to the corn crop of the country and therefore comprehensive and vigorous research programs relating to mechanical operations of crop production and commercial utilization should be continued by state and federal agencies.

21. That the machinery development program which is being conducted by state and federal agencies along crop production and utilization lines be continued. Since no one method or machine is adapted to all conditions, it is recommended that more complete information be made available in regard to cost and effectiveness of using rakes, burners, and other stalks and remnant disposal machinery and other devices to reduce hand labor.

22. That studies be made to determine the effects on farm incomes of different methods of harvesting and utilizing corn stalks, both commercially and on the farm.

23. That radical changes in agricultural practices should be recommended only if justified by the results of economic surveys including farm cost records.

24. That the State and Federal extension agencies take every opportunity by demonstrations, exhibits, and lectures to acquaint their constituencies with the gravity of the corn-borer problem, the nature of the insect and its work, and the methods of meeting the situation. The need of the cooperation of every grower in the regions adjacent to the infested area as well as within recognized corn-borer territory should be emphasized.

25. That Federal and State administrative authorities be urged to make available at frequent intervals up-to-date information regarding the general situation and the progress of investigations in the United States, Canada, and abroad, through the medium of bulletins, circulars and leaflets. Also, where advisable, mimeographed statements of progress be issued at frequent intervals to technical workers.

26. That the committee act as a clearing house in advancing corn borer control measures by obtaining opinions from the entomologists, agronomists, agricultural engineers, agricultural economists and others, as to the lines of research and other methods which should be pursued, with special reference to needed investigations not now under way and which may have a practical application to the problems.

27. That the fullest program of research be conducted along all lines offering promise of assistance and the fullest financial support for such research programs be provided, research being recognized as the basis of all progress in methods of control of the corn borer.

28. It is recommended that copies of all written reports or recommendations of the committee be made available to the Secretary of the United States Department of Agriculture and the Minister of Agriculture for Canada.

Respectfully submitted,

G. A. Dean
L. Caesar
D. J. Caffrey
C. J. Drake
J. J. Davis
For the Entomologists

L. E. Call
W. L. Burlison
J. F. Cox
R. M. Salter
F. D. Richey
For the Agronomists

C. O. Reed
A. L. Young
R. B. Gray
R. D. Barden
For the Agricultural Engineers

C. R. Arnold
H. C. M. Case
O. G. Lloyd
C. L. Holmes
H. R. Tolley
For the Agricultural Economists

Dr. Emil Truog presented the report from the Special Committee on Fertilizer Distributing Machinery which was accepted and the committee continued.

FERTILIZER DISTRIBUTING MACHINERY

The Committee feels that marked progress has been made in its work the past year. Two formal meetings were held, one at Columbus, Ohio, in April, and the other at West Baden, Indiana, in September. In accordance with the recommendation made by the joint committee last year the chairman made a survey of the experiments in progress on methods of fertilizer application at the different experiment stations and agricultural colleges. The results of this survey, the past reports and proceedings of the joint committee, together with an annotated bibliography of the subject of fertilizer application have been compiled by the secretary and chairman in a form suitable for publication. A generous offer of the National Fertilizer Association to defray the cost of printing this compilation was accepted and a copy of the printed publication has been sent to each member of the Society.

At the meeting in Columbus a standradized experiment on methods of corn fertilizaation for the northern states was formulated and a number of experiment

stations cooperated in carrying on this experiment the past year. The Committee has no report to make as yet regarding the results of the standardized experiment, but feels sufficiently encouraged to recommend that standardized cooperative experiments be extended the coming year. The Committee was pleased to find that the majority of the experiment stations wish to cooperate in the matter and are in favor of standardized experiments. Lack of funds seems to be the outstanding obstacle preventing many stations from attacking the problem as vigorously as they might.

At a meeting of the joint committee held November 21, 1928, sepcial consideration was given to the matter of the efficiency and performance of fertilizing distributing machinery. In order to expedite and correlate the work along all the different lines, a sub-committee made up of a representative from each society or organization participating in the work of the joint committee was appointed. This committee has been instructed to proceed at once to organize a complete program of procedure and to outline studies having to do with the testing of machinery, methods of fertilizer application, and all of the related problems involved.

In conclusion it is recommended that the Society continue the Committee for the ensuing year.

J. R. FAIN
F. E. BEAR
S. B. HASKELL
EMIL TRUOG, *Chairman*

Dr. F. E. Bear presented the report for the Special Committee on Fertilizers, which, upon motion, was accepted and the committee continued.

FERTILIZERS

During the past year, the Committee has cooperated with representatives of the fertilizer industry and others is an attempt to simplify the list of fertilizer analyses being offered for sale. A series of meetings to consider this problem having been called, the several members of the committee arranged to be in attendance at these meetings to assist in a program of standardization.

Early in the discussion it became apparent that it was desirable to adopt standard nutrient ratios rather than analyses since higher percentage materials are now available and a number of different complete-fertilizer analyses having the same nutrient ratios, can be produced.

THE FERTILIZER TRIANGLE SYSTEM OF SELECTING RATIOS

In selecting nutrient ratios, such as are required to cover the field of fertilizer need, difficulties arise in the choice because of the large number of ratios that are possible. At a meeting of agronomists, control officials, and representatives of the fertilizer industry and of the farm press held in Chicago, January 5 and 6, 1928, it was voted to adopt the principle of the decimal triangle system as the basis for the selection of fertilizer ratios. A report of this meeting, together with a discussion of the triangle method, is found in *The Fertilizer Greenbook* (Chicago), 9: No. 1, page 9, 1928, and in *The American Fertilizer* (Philadelphia), 68: No. 2, page 30, 1928.[1]

[1]See also Bot. Gaz., 50: 1–30, 1910. Ind. and Eng. Chem., 21. 1929.

Subsequently, the same principle was used in the selection of fertilizer ratios in the New England States. The central states group selected 11 ratios conforming to this principle, *viz.*, 2-6-2, 1-5-4, 2-4-4, 2-5-3, 3-4-3, 1-7-2, 1-6-3, 1-3-6, 0-2-8, 0-5-5, and 0-7-3. Subsequently, by agreement, four other ratios were added to the list. These are 5-3-2, 1-9-0, 0-6-4, and 2-8-0. At the New England States conference the 2-6-2, 1-5-4, 2-4-4, 2-5-3, 3-4-3, 1-7-2, 2-3-5, 4-3-3, and 4-2-4 ratios were chosen. Six of the ratios are common to both lists.

By the use of the decimal triangle, 36 complete fertilizer ratios and 27 two-nutrient ratios are possible. These are shown in the accompanying table. The range in choice would appear to be sufficient to meet the needs both of the producer and the consumer.

*Possible fertilizer ratios by use of triangle.**

N-P_2O_5	N-K_2O_5	K_2O-P_2O_5	N-P_2O_5-K_2O			
1-9-0	1-0-9	0-1-9	1-1-8	2-2-6	3-4-3	5-2-3
2-8-0	2-0-8	0-2-8	1-2-7	2-3-5	3-5-2	5-3-2
3-7-0	3-0-7	0-3-7	1-3-6	2-4-4	3-6-1	5-4-1
4-6-0	4-0-6	0-4-6	1-4-5	2-5-3	4-1-5	6-1-3
5-5-0	5-0-5	0-5-5	1-5-4	2-6-2	4-2-4	6-2-2
6-4-0	6-0-4	0-6-4	1-6-3	2-7-1	4-3-3	6-3-1
7-3-0	7-0-3	0-7-3	1-7-2	3-1-6	4-4-2	7-1-2
8-2-0	8-0-2	0-8-2	1-8-1	3-2-5	4-5-1	7-2-1
9-1-0	9-0-1	0-9-1	2-1-7	3-3-4	5-1-4	8-1-1

*It will be noted that these ratios are stated in numbers that total 10.

It is of interest to note that the Eastern States Farmers' Exchange and the Commercial Service Companies of the Ohio, Indiana, and Michigan Farm Bureaus have adopted the decimal-triangle-ratio system in selecting their fertilizer analyses for 1929.

The Committee wishes to bring this system of selecting fertilizer ratios to the attention of the Society. No formal action on this matter is requested at this time.

ORDER OF STATEMENT OF FERTILIZER ANALYSES

At the meeting held in Chicago January 5 and 6, 1928, previously referred to, it was agreed that, for the Central States, fertilizer analyses should be expressed in terms of nitrogen (N), phosphoric acid (P_2O_5), and potash (K_2O) and that these should be stated in the order named. The National Fertilizer Association, at its June 1928 meeting, adopted resolutions[2] to this effect and further resolved that the use of the term "acid phosphate" be discontinued, the word "superphosphate" being used in its stead.

At a sectional conference of agronomists, control officials, and representatives of the fertilizer industry and farm press held at West Baden, Indiana, September 5 and 6, 1928, resolutions[3] to the same effect were adopted. An additional resolution that fractional percentages in mixed fertilizer analyses be eliminated was also adopted. This does not apply to fertilizer materials.

The Committee recommends that the Society cooperate with the fertilizer industry and others concerned to the end that the above resolutions become effective throughout the United States.

[2]Amer. Fertilizer, 68: No. 13, p. 65, 1928.
[3]Amer. Fertilizer, 69: No. 6, p. 26, 1928.

INFLUENCE OF FERTILIZERS ON QUALITY OF CROPS

At the West Baden conference, previously referred to, the following resolution was adopted: "In view of the pressing need for a complete review of the data regarding the influence of fertilizers on the composition, quality and feeding value of crops and particularly because improved quality should bring the farmer a higher price; be it resolved that the Committee on Fertilizers of The American Society of Agronomy be requested to digest the available literature and prepare such a report in cooperation with the National Fertilizer Association."

It is recommended that the Committee be continued; that it give further consideration to the problems involved in standardizing fertilizer ratios that are to be offered for sale in the several regions of the United States; and that it proceed, in cooperation with the National Fertilizer Association, with the preparation of the report on fertilizers indicated above.

A JOURNAL OF FERTILIZER SCIENCE

The literature of the science of fertilizers is widely scattered among many publications. The reader in search of this literature is thus required to read many publications containing more or less extraneous subject matter. While it may well be argued that this requirement is not without its advantages, it is, nevertheless, true that the present trend is strongly toward specialized publications in the field of applied science.

The existing condition with reference to the disseminated character of fertilizer literature is a normal one which has developed naturally in a field of non-specialized publication. A survey of the situation indicates that very likely a stage has been reached which calls for the creation of a new journal devoted to the science of fertilizer materials and their use. It is now necessary for the student of fertilizers to keep in touch with a dozen or more scientific and semi-scientific journals which carry papers concerning fertilizers. An examination of the files of four of the leading journals of this group for the period of 1925–26 showed that they carried, on the average, 3 to 4 papers a month, which would be suitable for a journal of fertilizer science. It appears that at present 4 to 6 papers on fertilizer science are published monthly in American journals.

The fertilizer industry appears to be in the beginning of a tremendous development which probably will not reach a maximum within the present generation. The present interest in all phases of fertilizer science is unprecedented. Accompanying and even promoting the development of the fertilizer industry may be expected a marked increase in the contributions to fertilizer science. Is not this field of applied science growing so rapidly as to demand recognition as a separate entity and to require a special organ of publication?

Your Committee on Fertilizers is of the opinion that within a comparatively short time some group of workers in the field of fertilizer science will recognize the need and opportunity in this special field and take the necessary steps to meet the need and embrace the opportunity. The Committee is further of the opinion that such an undertaking would properly come within the scope of the activities of the American Society of Agronomy, and that by tradition and training of its personnel the Society is the proper body to foster and sponsor such an enterprise.

A journal of Fertilizer Science should function as a channel of publication of original papers dealing with the origin and properties of fertilizer materials and the use of them in the growing of plants. Fertilizer materials would be construed to include any substance added to the soil for the purpose of promoting

plant growth. Preference would be given papers giving results of original investigations. The journal should find a market in all scientific workers dealing with problems of plant production; in the group of professional workers which includes teachers and extension workers; and in all technical, professional and administrative workers of the fertilizer industry.

Your Committee has taken advantage of this opportunity to present this matter to the Society as one deserving consideration, but does not urge or expect formal action at this time. Criticism is invited.

Respectfully submitted,
J. W. GILMORE
A. B. BEAUMONT
J. C. PRIDMORE
FIRMAN E. BEAR, *Chairman.*

G. H. Cutler presented the following report for the Special Committee on Terminology of Seed of Improved Varieties appointed to cooperated with a similar committee from the International Crop Improvement Association. The committee was continued.

TERMINOLOGY OF SEED OF IMPROVED VARIETIES

The Committee on Terminology of Seed of Improved Varieties has attempted to do two things during the past year. First, to ascertain the nomenclature now in general use, and second, to canvass the opinion of plant breeders and agronomists regarding terms and definitions, from which a standard terminology might be developed.

As a result of these efforts, we are able to report as follows: (1) There is a general agreement for the need of a standard terminology of seed of improved varieties. (2) Some diversity of opinion exists as to whether the same term should be used to apply to a variety of crop, and a class of seed. (3) Some diversity of opinion exists on the terms to be used.

A meeting with the joint committee representing the International Crop Improvement Association was not arranged, though a conference of the joint committee chairmen took place.

The committee recommend that this brief progress report be accepted, and that the work of the committee be continued.

Respectfully submitted,
G. H. CUTLER, *Chairman.*
O. W. DYNES
F. A. BUSSELL
R. A. MOORE
CLYDE MCKEE

Dr. M. A. McCall reported for the Special Committee on the Annual Collection and Distribution of Crop Varietal Data. The report was accepted.

ANNUAL COLLECTION AND DISTRIBUTION OF CROP VARIETAL DATA

At the 1927 meeting of the Society, Prof. Clyde McKee of the Montana State College presented to the Executive Committee a plan for the annual collection and distribution of crop varietal data from all the experiment stations of the United States and Canada. Professor McKee's proposal was made after extensive correspondence with the crop specialists of all the states west of the Missis-

sippi River and with the Dominion Cerealist and others in Canada. He suggested that the Bureau of Plant Industry of the United States Department of Agriculture collect this material from the various state, federal, and dominion stations, have it mimeographed or otherwise prepared in suitable form, and distribute it by areas to the individual specialists as soon as possible after the end of each crop year. The plan called for maintaining station identity and individual credit in presenting the data, the function of the Bureau of Plant Industry to be that of a collecting and distributing agency.

The Executive Committee, after careful consideration of the plan, approved its general features and through the Secretary of the Society transmitted a request for this service to the Bureau of Plant Industry.

To carry out such a service entails considerable expense and responsibility. Without full and complete cooperation, it is useless to undertake it The service itself can have little value unless each station submits its data immediately after harvest so that the summaries can be issued on time The value of the service, however, in the rapid dissemination of information regarding new and promising crop material, especially that soon to be placed in commercial production, seems to justify the expense and the effort required. Such information continuously and generally available should aid in developing better coordination in the several crop improvement programs of the Country and should speed up progress. Recognizing its responsibility as a correlating agency in a national crop program, the Bureau of Plant Industry, through its Office of Cereal Crops and Diseases, is willing to undertake a trial of the service requested by the Society. The responsibilities and possible difficulties are so extensive, however, that it seems best to inaugurate the service only in a preliminary way to test its value and to determine how it best may be handled if it should be continued.

It is proposed to begin with the crop season of 1929 and to confine the first reports to a single crop, wheat. Because a start already has been made toward coordinating the wheat improvement programs of the States west of the Mississippi River, data will be included from plat varietal experiments in these States only. The magnitude of even this program may be realized from the fact that in this region there are between 50 and 75 individual stations where wheat varietal experiments are conducted. The details for collecting and distributing the summarized data will be worked out through correspondence with the stations and individuals concerned. This will be done well before the crop season, so that reports can be received and returned promptly and at such time as to be useful. Report and further recommendations regarding the trial will be made at the next annual meeting.

M. A. McCall, *Chairman*.

Dr. C. R. Ball reported for the standing committee on Agronomic Terminology and upon motion the report was accepted. This report will appear in a later issue of the Journal.

No report was received from the Committee on Standardization of Field Experiments.

R. G. Wiggans presented the report of the Committee on Varietal Standardization, which, upon motion, was accepted.

VARIETAL STANDARDIZATION

During the year, there were requests for the appointment of sub-committees for the registration of soybeans and cotton. The action taken at the annual meeting of the Society in Washington, D. C., November, 1926, approved a gen-

eral plan for the registration of varieties of merit for other agronomic crops, when such registration appeared desirable to the members of the Varietal Standardization Committee. With the approval of the president of our Society, a subcommittee was appointed for soybeans and a brief note regarding this action was published in Volume 20, No. 4, of our JOURNAL.

The members of the Varietal Standardization Committee were of the opinion that one of the requirements for cotton should be that the variety has attained practical homozygosity, by means of a system of controlled self pollination, which was carried on for a period of several years before the variety was eligible to be registered.

H. K. HAYES, *Chairman.*
L. H. NEWMAN
E. F. GAINES
J. H. PARKER
R. G. WIGGANS

No reports were presented by the Sub-committees on Varietal Registration of Barley, Corn, or Soybeans.

T. R. Stanton reported for the Sub-committee on Registration of Oats and the report was accepted.

REGISTRATION OF OAT VARIETIES

Since the publication of the last list of registered varieties in the JOURNAL for November, 1927, only one application for the registration of an improved variety was received by the sub-committee on the registration of oats. This variety was approved for registration by said sub-committee and also by the committee on varietal standardization. A record of its performance appears elsewhere in this number of the JOURNAL. A certificate of registration has been presented to the institution and official submitting the improved oat for registration.

T. R. STANTON, *Chairman.*
H. H. LOVE
E. F. GAINES

Dr. J. Allen Clark reported for the Sub-committee on Registration of Wheat and the report was accepted.

REGISTRATION OF WHEAT VARIETIES

Applications for the registration of improved wheat varieties have been requested and received by your Committee. The varieties which have been approved have been registered, and data are published in this issue of the JOURNAL of the Society. The varieties registered this year are Oro, Garnet, Reward, and Nabob. This is the first year that Canadian varieties have been registered.

J. A. CLARK, *Chairman.*
J. H. PARKER
L. R. WALDRON

No report was received from the Committee on Crops Teaching Methods.

M. F. Miller presented the report of the Committee on Soils Teaching Methods and the report was accepted.

THE TEACHING OF SOIL SCIENCE

During the last year your Committee has been engaged in the collecting and study of data bearing on the status of soil science teaching in the colleges of Canada and United States. Forty-nine institutions were examined and some rather interesting indications of progress were revealed.

For instance, the instruction now seems to center on the development of principles substantiated by agricultural practice, rather than merely on an orderly presentation of facts. Moreover the teaching apparently is becoming more and more psychological in nature. The adoption of such a method should not only increase the interest and effectiveness of the work but also result in economy of time. Another encouraging feature is the large amount of teaching done by those of professorial standing. This tendency of the men of higher rank to seek contact with the students, rather than delegate the work to instructors, should greatly aid in maintaining our soil teaching at its present high level.

The detailed report of the Committee covering these and other points has already been published in the JOURNAL for June, 1928.

H. O. BUCKMAN, *Chairman.*
M. F. MILLER
H. L. WALSTER

M. F. Miller reported for the Committee on the Chilean Nitrate of Soda Research Award. He made a brief statement of the purpose and the plan of administering the Award as adopted at the last annual meeting, and announced the winners of the Award, reading a brief statement regarding the scientific work of each. The winners were Dr. E. B. Fred, Professor of Agricultural Bacteriology, University of Wisconsin; Dr. Jacob G. Lipman, Director of the New Jersey Agricultural Experiment Station; Dr. T. L. Lyon, Professor of Soil Technology, Cornell University; and Dr. F. T. Shutt, Dominion Chemist, Ottawa, Ontario, Canada.

NITROGEN RESEARCH AWARDS

EDWIN BROUN FRED

Professor of Agricultural Bacteriology, University of Wisconsin

The work of Doctor Fred in nitrogen research deals with both nitrification and nitrogen fixation. In both of these fields he has made outstanding contributions.

His work on nitrification has done much to clarify the situation regarding the relation of organic matter to this process. In fact his work has led the way to a clarification of the whole subject of nitrogen-carbon relationships in the decay of organic matter and the formation of nitrates.

In his investigation of the process of nitrogen fixation by legume organisms Doctor Fred's work has been generally accepted as of very fundamental character. He made some of the earliest measurements of nitrogen fixation through legume organisms as these are influenced by soil acidity and liming. He worked out very carefully the influence of the reaction of the medium on nitrogen fixation and he developed the first practical classification of these bacteria in relation to their sensitivity to degrees of acidity. At the same time he has measured quantitatively the influence of these factors upon the nitrogen fixing activity of these organisms.

In the classification of legume bacteria, Doctor Fred has been a pioneer in showing that these organisms can be classified by the use of criteria other than

that of their adaptation to a particular host and his use of serological methods for classifying these organisms into groups having different nitrogen fixing powers represents a most important recent advance in our knowledge of this subject.

JACOB G. LIPMAN

Director, New Jersey Agricultural Experiment Station

Doctor Lipman's work in the field of nitrogen research is widely known. Not only has he personally conducted much of this research but he has been the inspiration for much that has been done by his students and colleagues. His work in this field has resulted in the following specific contributions:—

1. He has done significant work on the nonsymbiotic forms of bacteria including the isolation and classification of azotobacter.
2. He was a pioneer in clarifying our knowledge of the process of ammonification, emphasizing the soil constitution as a factor.
3. He has conducted most exhaustive measurements of the relative efficiency of different nitrogenous fertilizers, covering a period of almost thirty years and giving us a basis for judging the value of these materials.
4. He has made outstanding contribution to our knowledge of the influence of legumes vs non-legumes as green manures, on both limed and unlimed soils, particularly as these affect the nitrogen supply of the soil.

T. LYTTLETON LYON

Professor of Soil Technology, Cornell University

Doctor Lyon's outstanding contribution to nitrogen research has been to develop a fuller and more fundamental knowledge of the natural factors which control the supply of nitrates in the soil. Moreover, his work has emphasized the practical significance of this knowledge in the improvement of systems of soil management.

His investigations include:—

1. The influence of the cropping system, including both the preceding crops and the growing crop, on nitrate formation.
2. The influence of soil moisture and tillage operations on nitrate production.
3. The factors which contribute to losses of nitrates by leaching.
4. The influence of green manures on the supply of nitrates and of total nitrogen in the soil.
5. The effect of the mechanical condition of the soil on the availability of sodium nitrate.

FRANK T. SHUTT

Dominion Chemist, Ottawa, Canada

Doctor Shutt is undoubtedly the outstanding investigator in Canada in the field of nitrogen research. His most notable contributions have to do with the losses of nitrogen from the rich prairie soils of that country and with systems of soil management as they influence the soil nitrogen balance, in a northern climate. His work on the nitrogen losses from manure in storage, on the nitrogen content of the soil as it influences the growth of wheat, on the comparative value of nitrogenous fertilizers and his measurements of the nitrogen brought to the soil in rains, are all important contributions. In spite of his rather advanced age Doctor Shutt is in his laboratories daily and he is continuing his investigations with unabated enthusiasm.

President McCall presented diplomas and checks to Dr. Lipman and Dr. Lyon and announced that similar diplomas and checks would be sent to Dr. Fred and Dr. Shutt who were unable to be present.

Dr. J. G. Lipman reported progress for the Special Committee on the Organization of an American Section of the International Society of Soil Science. The committee was continued.

NOMINATING

Dr. W. P. Kelley presented the following report of the Nominating Committee: *Representatives on the Council of the A. A. A. S.*, H. K. Hayes and R. M. Salter. *Fourth Vice-President*, Dr. S. A. Waksman. *First Vice-President*, Prof. Clyde McKee. *President*, Dr. M. J. Funchess.

Upon motion the report was adopted and the secretary instructed to cast the unanimous ballot of the Society for these officers. This was done and they were declared elected.

RESOLUTIONS

J. D. Luckett presented the following resolution asking for cooperation of all agencies in preventing erosion, prepared by H. C. Smith, State Dept. of Agriculture, Montgomery, Alabama, which upon motion was adopted.

WHEREAS, Soil erosion is a constant national menace which must be considered from all angles in seeking a solution, and

WHEREAS, the greatest and most satisfactory measure of success depends on the cooperation of all agencies of nation, state and local organizations to effect a speedy means of saving untold wealth before it is destroyed.

THEREFORE, *Be It Resolved*, By the members of the American Society of Agronomy in 21st Annual Convention assembled at Washington, D. C.,

1. That we approve of all serious efforts being made to save our greatest national asset—the soil—from erosion.

2. That we especially commend the state-wide program put in force in Texas by the Federal Land Bank of Houston in causing terraces to be built and in otherwise inducing all farmers, who secure loans from them, to do all in their power to prevent losses from erosion and that we respectfully recommend their project to the consideration of all other Federal Farm Loan Banks, and to all other agencies engaged in loaning money to farmers on land or for production credit.

FURTHERMORE, We respectfully invite all agencies of national government, all agencies of state government and all organizations interested in agriculture or engaged therein and all owners of land and tillers of the soil, to unite in all enterprises and movements designed to save our soils from destruction.

LASTLY, We do this realizing that the safety of all agricultural credits, the stability and permanence of our national life and the prosperity of our farmers depends on these features, and on the constant active cooperation of all farmers in saving their soils for themselves and for their posterity.

R. W. THATCHER, *Chairman*.
J. D. LUCKETT

H. R. Smalley moved that the Executive Committee consider the desirability of organizing a Fertilizer Section of the Society. Motion carried.

Meeting adjourned.

P. E. BROWN, *Secretary*.

PROGRAM

THURSDAY, NOVEMBER 22

8:30 A.M.—SOCIAL HOUR
9:30 A.M.—MEETING CALLED TO ORDER

President A. G. McCALL

APPOINTMENT OF COMMITTEES

SYMPOSIUM: "SOIL ORGANIC MATTER AND GREEN MANURING"

Leader: J. G. LIPMAN, New Jersey Agricultural Experiment Station

1. Relation of soil type and climate to the occurrence and distribution of organic matter (20 minutes)
C. F. MARBUT, Bureau of Soils, U. S. D. A.
Discussion: P. E. Brown (10 minutes)
2. Organic matter problems in humid soils (20 minutes)
T. L. LYON, Cornell University
Discussion: F. E. Bear (10 minutes)
3. Organic matter problems under dry farming conditions (20 minutes) J. C. RUSSELL, University of Nebraska
Discussion: M. C. Sewell (10 minutes)
4. Organic matter problems in irrigated soils (20 minutes)
P. S. BURGESS, University of Arizona
Discussion: G. R. McDole (10 minutes)
5. Chemical and microbiological principles underlying the use of green manures (20 minutes)
S. A. WAKSMAN, New Jersey Agricultural Experiment Station
Discussion: J. E. Greaves (10 minutes)
6. Green manuring and its application to agricultural practices (20 minutes)
A. J. PIETERS and R. McKEE, Bureau of Plant Industry, U. S. D. A.
Discussion: T. C. Johnson (10 minutes)

Soils Section Program

THURSDAY, NOVEMBER 22

2:00 P.M.

SYMPOSIUM: "APPLICATION OF BASE EXCHANGE METHODS"

Leader: F. W. PARKER, Alabama Polytechnic Institute

1. The determination of the exchange capacity of soils
W. P. KELLEY, University of California
2. The origin, nature, and isolation of the inorganic base exchange compound of soils E. TRUOG, University of Wisconsin
3. The determination of exchangeable hydrogen in soils
F. W. PARKER, Alabama Agricultural Experiment Station
4. Methods for studying exchangeable bases in calcareous soils
P. S. BURGESS, Arizona Agricultural Experiment Station
5. The use of artificial zeolites in studying base exchange phenomena
O. C. MAGISTAD, Arizona Agricultural Experiment Station

Extension Section Program

THURSDAY, NOVEMBER 22

2:00 P.M.

SYMPOSIUM: "LIME"

Leader: O. S. FISHER, U. S. Department of Agriculture

1. The portable soil laboratory and the Ohio method of testing soils for acidity — EARL JONES, Ohio State University
2. Lime surveys for use in Illinois and testing for lime requirement — C. M. LINSLEY, University of Illinois
3. The Kentucky marl beds as a source of lime material — S. C. JONES, University of Kentucky
4. The development of equipment for dredging marl from the Michigan lakes — L. F. LIVINGSTON, Michigan State College

THURSDAY, NOVEMBER 22

6:30 P.M.

Annual Dinner—Willard Hotel

PRESIDENT'S ADDRESS:
"A NATIONAL PROGRAM OE SOIL RESEARCH"
A. G. MCCALL, Bureau of Chemistry and Soils U. S. Department of Agriculture

BUSINESS MEETING
Officers' Reports
Committee Reports
Election of Officers
New Business
Announcements

Soils Section Program

FRIDAY, NOVEMBER 23

8:30 A.M.

SYMPOSIUM: "SOIL EROSION"

Leader: H. H. BENNETT, Bureau of Chemistry and Soils

1. Erosion in the Orient as related to soil conservation in America (30 minutes) — W. C. LOWDERMILK, U. S. Forest Service
2. The results and significance of the spur (Texas) runoff and erosion experiment (30 minutes) — R. E. DICKSON, Texas Agricultural Experiment Station
3. Erosion on range land (illustrated) (30 minutes) — W. R. CHAPLINE, U. S. Forest Service
4. The prevention of the erosion of farm lands by terracing (25 minutes) — C. E. RAMSER, U. S. Department of Agriculture
5. The necessity for soil conservation (35 minutes) — A. K. SHORT, Federal Land Bank of Houston, Texas
6. Discussion of papers

Crops Section Program

FRIDAY, NOVEMBER 23

8:30 A.M.

SYMPOSIUM: "TOBACCO RESEARCH"

Leader: W. L. SLATE, JR., Connecticut Agricultural Experiment Station

1. The chemical approach to the study of problems of tobacco fertilization — D. E. HALEY, Pennsylvania State College
2. The effect of other crops on tobacco — J. P. JONES, Massachusetts Agricultural College
3. Tobacco as an indicator plant in soil studies — M. F. MORGAN, Connecticut Agricultural Experiment Station
4. Nutritional problems in bright tobacco — E. G. MOSS, U. S. Department of Agriculture
5. Nutritional deficiency studies — J. E. MCMURTREY, U. S. Department of Agriculture
6. A water culture technic for studies in tobacco nutrition — A. B. BEAUMONT, Massachusetts Agricultural College
7. Soil reaction studies — P. J. ANDERSON, Connecticut Agricultural Experiment Station
8. Factors affecting nicotine content — C. W. BACON, U. S. Department of Agriculture

FRIDAY, NOVEMBER 23

2:00 P.M.

OPEN SESSION FOR PAPERS ON SOILS AND CROPS

1. A comparison of good and poor alfalfa soils — R. R. MCKIBBIN, MacDonald College
2. The effects of certain injuries upon the leaves and stalks of corn plants upon weights produced of grain and vegetation — A. N. HUME, South Dakota State College
3. Soil and land valuation short courses — W. H. STEVENSON and P. E. BROWN, Iowa State College
4. Inheritance of immunity from black stem rust, yield, and protein content in Hope wheat crosses with susceptible and resistant varieties. — J. ALLEN CLARK and E. R. AUSEMUS, Bureau of Plant Industry
5. Recent trends in fertilizer consumption in Europe — H. R. SMALLEY, National Fertilizer Association
6. The production of artificial manure from oats straw under control conditions — P. E. BROWN and F.B. SMITH, Iowa State College
7. Correlation between electromotive series and the absorption of electrolytes and the relation of these to nutrition — H. P. COOPER, and J. K. WILSON, Cornell University
8. Some errors peculiar to forage crop experimentation — L. W. KEPHART and E. A. HOLLOWELL, Bureau of Plant Industry
9. Studies on iron accumulations in the nodal tissues of dent corn plants — JOHN F. TROST, Purdue Agricultural Experiment Station.

A conference believed to be of considerable significance for the hard red winter wheat belt was held at Manhattan, Kansas, on November 8, 1928, for the purpose of considering ways and means by which research relative to the problems of wheat growers in this belt may be increased and made more effective. Farmers, grain dealers, millers, bakers, bankers, newspaper men, and representatives of railroads, state boards of agriculture, crop improvement associations, and agricultural experiment stations of the five states of Nebraska, Colorado, Oklahoma, Texas, and Kansas and of the United States Department of Agriculture to the number of nearly 200 were present. A total of nine addresses called attention to the principal wheat-producing, processing, and marketing problems of these five states. The program was followed in the evening by a banquet which in turn was followed by informal discussions and reports of committees.

The program committee reported that there is an urgent need for more research work relating to hard red winter wheat. This is indicated by a declining soil fertility, increasing damage from plant diseases, and changing economic conditions which have brought on new problems. Some of the specific problems which in the judgment of the committee seemed especially to merit attention are certain soil management and tillage problems that have been introduced or emphasized by the combine, such for example as the utilization of straw; the use of the one-way disk or wheat land plow; the control and conservation of water and the relation between water stored in the soil and yield; the control of Hessian fly, stinking smut, and foot rots; the production of better varieties, especially with reference to quality, early maturity, tendency to lodge and shatter, resistance to various insects and diseases and winterhardiness; such economic problems as credit and storage facilities, and the need for additional protein and inspection laboratories in order to facilitate the reflection of quality premiums to individual farmers; and such agricultural engineering problems as removal of excess water from wheat on or near the farm, the relation of type and size of bin to heating of damp wheat, and certain mechanical and power requirements for preparation of the ground and harvesting. The committee went on record to the effect that an understanding of a given phenomenon is often as important as a demonstration of the phenomenon itself, and hence that the need for fundamental research in relation to these problems should not be neglected.

It was estimated that at least $300,000 a year would be needed to study these problems effectively. The committee recommended the appointment of a permanent Research Conference consisting of representatives from the allied industries and the experiment stations of the five principal hard red winter wheat producing states and the United States Department of Agriculture.

The finance committee recommended that the advantages of increased research and the need for its more adequate financing be brought to the attention of the state legislatures and the Congress of the United States, and further, that all interested agencies join in a request to the federal government for a sum of $150,000 to be added to the appropriations of the United States Department of Agriculture for the fiscal year 1929-30 for research work related to the above problems, and also that they lend every possible assistance to the agricultural colleges and the experiment stations of the five states in such requests as they may make for increased appropriations for research.

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President M. J. Funchess has appointed the following standing committees of the Society for the coming year.

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